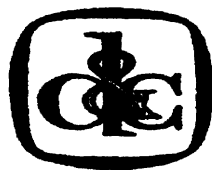


Rees's
**Manufacturing
Industry**
(1819-20)

Volume One

A selection from
*The Cyclopaedia; or Universal
Dictionary of Arts, Sciences and Literature*
by
ABRAHAM REES

Edited by Neil Cossons



DAVID & CHARLES REPRINTS

first published serially 1802–20

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Introduction

Abraham Rees's monumental *Cyclopaedia, or Universal Dictionary of Arts and Sciences* . . . which appeared in parts between 1802 and 1819 was one of the first works of its kind to be published in English which gave more than passing reference to contemporary industry and technology. Indeed, 'Rees' is one of the most valuable and comprehensive sources of information on manufacturing processes and techniques in the early years of the nineteenth century and as such is highly regarded by students and scholars of economic, industrial and technological history as a basic and fundamental starting point for further and more specific researches. It forms a major work of reference on many other subjects too, with great attention being paid to English biography, a massive and detailed coverage of botany at an important period in the advancement of botanical research, and articles on agricultural husbandry, astronomy, horology and naval architecture, for example, all regarded today as valuable, and in some cases unique, sources of summary information.

This new edition is an attempt within the limits of modern reprint technique to provide as complete a collection as possible of the Rees entries relating to industry and technology. By maintaining an alphabetical format it has been possible to provide a comprehensive but at the same time concentrated selection of relevant material assembled from the thirty-nine volume bulk of the original into an easily referred to form. There have been some minor losses, however, resulting largely from the technical problems of reprinting a work made up of individual articles of widely varying size. Small entries of less than half a column have, unless of exceptional significance, been omitted as have numerous one or two line dictionary definitions hardly appropriate to the scale of the major articles. Thus this new edition consists of those articles for which Rees is well known in the field of industrial and technological history, accompanied by the corresponding illustrations.

Abraham Rees was born in Llanbrynmair, Montgomeryshire in 1743, the son of Lewis Rees an independent minister and pillar of the nonconformist cause in South Wales. Abraham was educated for the ministry in London, entered in 1759, and subsequently held a number of positions as tutor in mathematics and natural philosophy, tutor in Hebrew and mathematics, and assistant preacher, all of them in London. In 1783 he went to the pastorate of the Old Jewry congregation, a position he retained until his death in 1825. In 1775 he received the degree of doctor of divinity from Edinburgh University.

Rees's work as a cyclopaedist began in the 1770s when he re-edited the cyclopaedia of Ephraim Chambers originally published in two volumes in 1728. The success of the new Rees edition, published in 1778, and reprinted in 1788–91, gained him recognition in 1786 when on 1 June of that year he was elected a Fellow of the Royal Society. The certificate of candidature described him thus: 'Abraham Rees, of the Old Jewry, D.D., Editor of the new and improved Edition of Chamber's Cyclopaedia now completed and a Gentleman well versed in the different Branches of Mathematics and Natural Philosophy, . . .' Later Rees was elected a fellow of the Linnean Society and the American Society. His success with Chambers led Rees to project a similar but more comprehensive work on a much larger scale and the first part of *The New Cyclopaedia, or Universal*

Dictionary of Arts and Sciences . . . Biography, Geography, and History, etc, was issued on 2 January 1802. It was completed, in forty-five volumes, including six volumes of plates, in August 1820. Congratulated by his friend John Evans on the completion of his gigantic task, Rees wrote in reply: 'I thank you, but I feel more grateful that I have been spared to publish my four volumes of sermons.' These he completed in 1821.

Rees's Cyclopaedia was issued in parts, two of which formed a volume. These parts appeared at irregular intervals and on completion of the work a set of title pages was issued bearing the date of the last, namely 1819 for thirty-nine volumes of text, and 1820 for six volumes of plates.

Various attempts have been made to define the dates of issue of the sections of Rees, the most complete being published by Benjamin Daydon Jackson in 1895—*An Attempt to Ascertain the Actual Dates of Publication of the various parts of Rees's Cyclopaedia*. This chronology is based on a variety of evidence but nevertheless gaps exist. Jackson's main sources were the *Monthly Literary Advertiser* published on the 9th or 10th of each month and a rare set of the *Cyclopaedia* in their original unbound state. Although Longmans, the original publishers, had no information on the dates of publication, and no dates appeared on the individual parts, a list of new books by the publisher was printed on the inside cover of each part, generally dated and in some cases by the day of the month.

These two authorities added together still left many gaps which in part have been filled by evidence from the plates issued with each part. Unfortunately the plate dates vary widely, even within a single issue, and in some cases no date whatever is provided—only, 'Published as the Act directs, by Longman', etc. Within one pair of covers dates as far apart as 1805 and 1813 occurred.

The custom of dating plates arose in order to preserve the copyright in the engraving. In 1735 an Act, (8 George III, c 13) specified this and stated that the designer ' . . . shall have the sole right and liberty of printing and reprinting the same for a term of fourteen years, to commence from the day of the first publishing thereof, which shall be truly engraved with the name of the proprietor on each plate, and printed on every such print or prints'. In 1767 the term of years was extended to twenty-eight, the occasion being to protect the engravings after Hogarth's pictures. A decision of Chief Justice Best, made in 1816, shows that the law had not been relaxed although the practice, as shown in the *Cyclopaedia*, had. The Copyright Act of 1842 superseded these provisions, thenceforth every map or engraving in a copyrighted book shared in the overall protection.

The following list propounded by B. D. Jackson is broken down under the volume and its part and the running number of each part as frequently quoted in the *Monthly Literary Advertiser*. Next follows the contents—the first and last article in each part, then the nearest date assigned to it, authenticated by the source of information. The initials *M.L.A.* indicate *Monthly Literary Advertiser*, and are probably the most accurate. Next the booklists on the inside covers provide a closing date for the issue of each part. Finally, a few dates have been ascribed from amongst the plates in each part, the latest date on a plate being given in each case. These latter are probably worth very little.

VOL.	SECT.	PART.	CONTENTS.	DATE.	AUTHORITY.
1	I.	1	A—Agoge	2 Jan., 1802	Book List.
	II.	2	Agogliastro—Amaranthoides ...	2 May, 1802	Last Plate.
2	I.	3	Amaranthus—Antimony	2 Sept., 1802	Do.
	II.	4	Antimony—Arteriotomy	2 May, 1803	Do.
3	I.	5	Artery—Babel-mandeb	— Aug., 1803	Do.
	II.	6	Babenhausen—Battersea	1 Feb., 1804	Do.
4	I.	7	Battery-point—Björnstall	1 Aug., 1804	Do.
	II.	8	Biot—Bookbinding	1 Feb., 1805	Book List.
5	I.	9	Bookkeeping—Brunia	1 Sept., 1805	Last Plate.
	II.	10	Brunia—Calvart	?	
6	I.	11	Calvary—Cape of Good Hope ...	17 Feb., 1806	Book List.
	II.	12	Cape of Good Hope—Castræ ...	23 May, 1806	Do.
7	I.	13	Castramentation—Chalk	30 Sept., 1806	Do.
	II.	14	Chalk—Chronology	1 Jan., 1807	Do.
8	I.	15	Chronometer—Clavaria	— Jan., 1807	M.L.A.
	II.	16	Clavaria—Colisseum	1 Aug., 1807	Book List.
9	I.	17	Collision—Congregation	— Dec., 1807	Do.
	II.	18	Congregation—Corne	1 March, 1808	Do.
10	I.	19	Cornea—Croisade	— May, 1808	M.L.A.
	II.	20	Croisade—Czyreassy	27 June, 1808	Book List.
11	I.	21	D—Deluge	24 Sept., 1808	Do.
	II.	22	Deluge—Dissimilitude	28 Nov., 1808	Do.
12	I.	23	Dissimulation—Dynamics... ..	— March, 1809	M.L.A.
	II.	24	Dynamics—Eloanx	— June, 1809	Do.
13	I.	25	Elocution—Equation	14 Aug., 1809	Book List.
	II.	26	Equation—Extremum	— Dec., 1809	M.L.A.
14	I.	27	Extrinsic—Fibro-cartilage	— Apl.(?), 1809	Book List.
	II.	28	Fibro-cartilage—Food	1 Feb., 1810	Last Plate.
15	I.	29	Food—Froberger	23 June, 1810	Book List.
	II.	30	Frobisher—Generation	8 Oct., 1810	Do.
16	I.	31	Generation—Gniewe	— Dec., 1810	M.L.A.
	II.	32	Groien—Gretna-Green	— Jan., 1811	Do.
17	I.	33	Gretry—Hatfield-Regis	?	
	II.	34	Hatfield-Regis—Hibe	12 April, 1811	Book List.
18	I.	35	Hibiscus—Huysum	1 May, 1811	Last Plate.
	II.	36	Huzanka—Increment	1 Aug., 1811	Book List.
19	I.	37	Increment—Josephus	1 Sept., 1811	Last Plate.
	II.	38	Josephus—Kilmes	— Dec., 1811	Book List.
20	I.	39	Kiln—Lauremberg	?	
	II.	40	Lauremberg—Lights	— March, 1812	Book List.
21	I.	41	Light-house—Longitude	?	
	II.	42	Longitude—Machinery	?	
22	I.	43	Machinery—Manganese	?	
	II.	44	Manganese—Macheson	— Oct., 1812	Book List.
23	I.	45	Matthew—Metals	— Dec., 1812	Do.
	II.	46	Metals—Monsoon	— April, 1813	M.L.A.
24	I.	47	Monster—Muscle	?	
	II.	48	Muscle—Newton	?	
25	I.	49	Newtonian—Oleinæ	?	
	II.	50	Oleinæ—Ozunicze	?	
26	I.	51	P—Passiflora	?	
	II.	52	Passiflora—Perturbation	— Dec., 1813	Book List.
27	I.	53	Pertussis—Picus	— March, 1814	Do.
	II.	54	Picus—Poetics	?	
28	I.	55	Poetry—Preaching	?	
	II.	56	Preaching—Punjoor	?	
29	I.	57	Punishment—Ram	?	
	II.	58	Ram—Repton	— Dec., 1814	Book List.
30	I.	59	Republic—Rock	?	
	II.	60	Rock—Rzemien	— 1815	Last Plate.

VOL.	SECT.	PART.	CONTENTS	DATE.	AUTHORITY.
31	I.	61	S—Sarabanda	?	
	II.	62	Sarabanda—Scotium	— Sept., 1815	Book List.
32	I.	63	Scotland—Shammy	— March, 1816	<i>M.L.A.</i>
	II.	64	Shammy—Sindy	?	
33	I.	65	Sine—Sound	— May, 1816	Book List.
	II.	66	Sound—Starboard	— July, 1816	Do.
34	I.	67	Starch—Stuart	— Nov., 1816	<i>M.L.A.</i>
	II.	68	Stuart—Szydlow	20 Dec., 1816	Do.
35	I.	69	T—Testudo	— Feb., 1817	Book List.
	II.	70	Testudo—Toleration	?	
36	I.	71	Tolerium—Tumours	— Aug., 1817	Book List.
	II.	72	Tumours—Vermelho	24 Oct., 1817	<i>M.L.A.</i>
37	I.	73	Vermes—Union	23 Dec., 1817	Do.
	II.	74	Union—Watecoo	?	
38	I.	75	Water—Whitby	28 May, 1818	<i>M.L.A.</i>
	II.	76	Whitby—Wren	31 July, 1818	Do.
39	I.	77	Wren—Zyto: Aam-Baldwin	— Jan., 1819	Do.
	II.	78	Baldwin—Zollikofer. Titles	— Nov. 1819	Do.
	III.	79	Titles, Preface, Plates	?	
	Part A		Plates to complete.	?	
	„ B		Do.	?	
	„ C		Do.	?	
	„ D		Do.	?	
	„ E		Do.	?	
	„ F		Do.	(“last”) Aug., 1820	<i>M.L.A.</i>

Preface

THE CYCLOPÆDIA, which has been the production of the incessant labour of almost twenty years, is now completed, very much to the relief of the Editor's mind, and, as he hopes, to the satisfaction of the Public. To the candid judgment of its numerous readers, the Editor submits the work, assuring them, that, on his part, no pains have been wanting to render it worthy of their approbation. If he had foreseen the time and attention which the compilation and conduct of it required, and the unavoidable anxiety which it has occasioned, he would probably never have undertaken it. But habits of application, and some degree of experience in a work of this nature, disposed him to embark in it, and enabled him to overcome the difficulties that presented themselves to his view in his further progress. He hopes that he may be allowed to say, that an early and long-continued attachment to scientific pursuits, and a desire of serving the cause of Literature and Science, had no inconsiderable influence in directing his views to this object, and encouraging his perseverance in the accomplishment of it. He ought also to acknowledge, that the candour with which his labours, on this as well as on a former similar occasion, were received by the Public, and the expressions of approbation with which they were honoured in the course of sixteen years, afforded a very powerful inducement to unremitting assiduity and exertion. The Proprietors also, who had undertaken this work without any patronage besides that of the Public, and who were advancing large sums towards rendering it worthy of that patronage, were liberal in their co-operation, and in enabling the Editor to procure every kind of assistance, which he might find to be necessary and useful. They employed artists of the first reputation in their respective departments, whose performances have given a peculiar character to this work. The Proprietors and Editor were likewise honoured by connection and acquaintance with persons, eminently distinguished in those branches of science to which they had devoted their talents; and these persons not only consented to be co-adjutors, but to give celebrity to the work by allowing their names to be annexed to it, whilst they were enhancing its importance and value by their contributions. Although the Editor cannot decline availing himself of the reputation which the Cyclopædia must acquire from the established and well-known character of his associates,

and with this view presenting their names to the Public, he does not wish to rob them of any portion of fame that belongs to them, in order to enrich himself. Notwithstanding all the assistance which he has received, and which he thus gratefully and respectfully acknowledges, his own responsibility furnishes a large demand on the candour of the Public ; nor will those who duly consider, that he has devoted almost twenty years of his life, measured not by fragments of time, but by whole days of twelve or fourteen hours, to the completion of his undertaking, and in so doing impaired his health and constitution, be indisposed to exercise that liberality in their estimate of his labours which he solicits. He is not unapprised of defects and imperfections ; and if he were to begin the *Cyclopædia de novo*, he could improve it. Science is progressive ; and since the commencement of this work, its advances in several departments have not been inconsiderable. The Editor has endeavoured to watch its steps, and to incorporate in his pages every discovery and improvement that has attended its progress. He now presents his work, in its finished state, at the bar of the Public, anxiously but not timidly waiting a favourable decision. He begs leave, however, to suggest, that he does not consider himself as responsible for the opinions advanced by his co-adjutors in the articles which they have furnished, any more than for those which occur in extracts from printed works. Some of these seem to him to be erroneous ; and they are actually controverted and contradicted in other parts of the *Cyclopædia*, where the mention of them occurs. As he could not prescribe limits to the articles supplied by his co-adjutors, he could not presume to prohibit a statement of their own sentiments on the subjects of the articles which they contributed. In every case the reader will form his own judgment.

The names of most of his co-adjutors have been already published on the covers of several parts of the work ; but after he has again recited them, every reader will be able to assign to each, so well known in the circle of science, the articles of any extent and of principal importance, which he has furnished. Under each head, the arts and sciences being arranged in alphabetical order, will be mentioned the names of those to whom the Editor is indebted for contributions ; though in some cases the number is small and the articles are short, whilst in others they are more numerous and more extended. Many of these articles have been considerably enlarged in consequence of the Editor's own researches. His own additions are so incorporated with the communications of his friends, that it would not be easy to distinguish them without a minuteness of detail, which, as he conceives, would be tedious and uninteresting. *Agriculture*, Dr. Dickson. — *Algebra* and *Analysis*, Barlow, Bonnycastle, and Pond. — *Anatomy* and *Physiology*,

Abernethy and Lawrence. — *Comparative Anatomy*, Macartney, Lawrence, and Clarke. — *Annuities*, W. Morgan. — *Antiquities*, H. Ellis and Strutt. — *Architecture*, Porden, E. Aikin, P. Nicholson, Dr. Milner, and Webster. — *Astronomy*, Bonnycastle and Pond. — *Astronomical Instruments*, Rev. Dr. Pearson. — *Biography*, Sir J. E. Smith, Dr. Burney, Dr. Malkin, and Dr. T. Rees. — *Botany*, Sir J. E. Smith, Dr. Woodville, Rev. Mr. Wood. — *Canals*, Farey, senior. — *Chemistry*, Aikin, Sylvester, Dalton, Brande, Dr. Marcet, Sir Humphrey Davy, Dr. C. Taylor, and Dr. Davy. — *Conic Sections and Curvilinear Geometry*, Ivory. — *Drawing*, Howard. — *Dynamics*, Cavallo. — *Education*, Dr. Carpenter. — *Electricity*, Cavallo and Cuthbertson. — *Engraving*, Landseer. — *Entomology, Conchology*, and several other articles of *Natural History*, Donovan. — *Exchange, Standard, Coinage, and Weight*, Dr. Kelly. — *Blast and Blowing Furnaces*, Mushett. — *Geology*, Koenig, Bakewell. — *Geography*, Tooke, Hinckes. — *Geometry*, Barlow, Ivory. — *Grammar*, Dr. Jones. — *Heraldry*, Sir G. Naylor. — *History, English*, S. Turner and Owen Pugh. — *Horology*, Rev. Dr. Pearson. — *Language*, Dr. Carpenter; Dr. Jones. — *Magnetism*, Cavallo. — *Manufactures*, Duncan, J. Thomson, Parkes, and Farey, junior. — *Mechanics and Machinery*, Cavallo, Farey, junior. — *Medicine*, Dr. Bateman and Dr. Henderson. — *Mental Derangement*, Dr. Haslam. — *Meteorology*, L. Howard, Dalton, and Dickson. — *Midwifery*, Dr. Bland. — *Mineralogy*, Koenig, Bakewell. — *Mining*, Taylor. — *Naval Architecture*, Glover. — *Navigation*, Mackay. — *Music*, Dr. Burney and Farey, senior. — *India Mythology*, Major Moor. — *Mental and Moral Philosophy*, Dr. Carpenter. — *Painting*, Russell, Opie, Ottley, and Phillips. — *Prosody*, H. Parker. — *Sculpture*, Flaxman, P. Hoare, and Bacon. — *Surgery*, Blair, who also furnished the article *Cipher*, and S. Cooper. — *Topography*, Britton. — *Versification*, H. Parker ; — and a variety of *Miscellaneous* articles by Joyce, Ellis, Fletcher, Howard, Clarkson, and several other gentlemen, who were occasional contributors, and whose names it is needless to mention. To Mr. S. Bevan and some other literary and scientific friends, the Editor is indebted for the assistance which they have afforded him in suggesting articles that had been omitted, and that have been supplied in the *Addenda*. Dr. Thomas Rees has, towards the close of the work, paid particular attention to the arrangement of the Plates. He has also drawn up a digested catalogue of them, together with an alphabetical index of the subjects which they comprise ; and added such explanations, and corrections of references, as appeared to be necessary or desirable, after a minute and careful collation, made in conjunction with the Editor, of every Plate, with the printed letter-press to which it pertained. The Editor and Proprietors of this work are also indebted to

Mr. Donovan, for the General Systematic Arrangement of the Plates of Natural History.

The general plan upon which this work has been conducted, and which was stated in the Advertisement that announced the publication of it, seemed to the Editor, after some experience in this department of literary labour, and after consulting several competent judges, the most suitable to the nature and design of a Scientific Dictionary. Whatever may be the advantage resulting from separate dictionaries appropriate to each particular science, which is the plan of the FRENCH ENCYCLOPÉDIE, or from distinct treatises introduced in a dictionary of one alphabet, according to some modern compilations of this kind, the inconvenience and perplexity that attend the multiplication of alphabets, whether they occur in different serieses of volumes, or in the form of an index at the close of each treatise, will furnish an objection against this mode of arrangement, which it will not be easy to obviate. In a work of such magnitude as the French Dictionary, consisting already of between 100 and 200 volumes, and of undetermined extent, the best treatises that have been written, or that may be written, on each subject, may be introduced, and the work itself may be a complete library, and supersede the necessity of recurring to any other. But in a publication of limited compass, such as booksellers may undertake, and the general class of readers purchase, it is hardly possible to combine separate articles, sufficiently instructive, with treatises equally comprehensive and complete. To those who usually consult dictionaries for information, this plan, we are persuaded, is by no means the most eligible. If they wish to extend their knowledge beyond the limits to which a dictionary must necessarily restrict it, they will recur to appropriate treatises for the purpose; and the dictionary should furnish them with the necessary references. A dictionary is intended for communicating knowledge in an easy and expeditious manner; and it is desirable that the several articles should be so full and comprehensive, as to afford sufficient instruction on the subjects to which they relate, without the necessity of recurring to another dictionary, or to an index, for further information. It may be said, indeed, that the sciences are thus mutilated and mangled; and that it is impossible to preserve their unity without discussing each in a separate treatise. We readily allow, that this is an inconvenience, inseparable from the form of a dictionary; but at the same time we think that this may be remedied in a considerable degree by that kind of ramification of the principal subject, which, with suitable references, will lead the reader to subordinate articles, that form, by their mutual connection and dependence, an aggregate or whole, superseding in all common cases the necessity of a distinct treatise. These

references, when judiciously distributed and arranged, will serve, like the index of a book, but much more effectually, to conduct the reader from one subject to another : they will enable him to perceive their relation to each other ; and they will direct him how to collect and combine the dispersed parts of any science into one entire and regular system. Each article will afford him, as it were, a distinct lecture ; and he may pursue the same course of study by the means now suggested, or vary it as he thinks proper. Upon the whole, the advantage of separate treatises under each head of science, such as the limits of a dictionary will allow, seems to be more imaginary than real ; more especially as the want of them may be supplied in the manner that has been mentioned.

In conformity to our proposed plan, it has been our endeavour to give, under each distinct head of science, an historical account of its rise, progress, and present state, concisely and yet as comprehensively as our limits and our sources of information would allow ; to refer to those articles in which the discussion of them occurs, and to point out such publications as afford further information. References of this kind are introduced under each separate article, wherever they are thought to be necessary and useful ; and thus the reader is able to form his judgment concerning the authorities upon which the compilers of the several articles depend ; and if he shall have opportunity or inclination, he may recur to them for himself.

Whilst the Editor and his co-adjutors in this work have availed themselves of the assistance which other similar dictionaries have afforded them, they have not contented themselves with mere transcripts ; they have resorted as much as possible to original writers, which they have been enabled to do by the facility of their access to large libraries ; and by the citations which they subjoin to the several articles, the Public will judge of the extent of their research, and of the industry and labour which they have bestowed on this compilation. In their account of the arts and manufactures, they have consulted the artisans and manufacturers themselves, and derived from them every kind of information that was likely to conduce to the credit and utility of the work : and this they have not been able to do without incurring a very considerable expence.

Some apology may, perhaps, be thought necessary for the extension of this work beyond the limits first proposed. When it was determined to introduce biography, as well as geography, topography, and history, upon a larger scale than the Proprietors and Editor had at first intended, principally

in compliance with the wishes of intelligent and esteemed subscribers, the enlargement of it became indispensable. To his co-adjutors, whose assistance was highly important, the Editor could not presume to prescribe limits, which would have depreciated the value of the articles which they contributed, and within which, for their own reputation, they would not have consented to be confined, and of course the work would have been deprived of the benefit of their contributions. This circumstance could not fail to occasion an enlargement of the Cyclopædia; but it was proportionably enhanced in value; and the Editor is satisfied, that the purchasers will not ultimately regret the augmentation of expence. The plates likewise have been multiplied far beyond the original intention of the Proprietors, because new and unthought-of subjects were introduced in the progress of the work; but as these plates constitute a character of excellence peculiar to this Cyclopædia, it is thought that the circumstance of their being additional embellishments of the work, besides that of their being indispensable as explanatory of the articles to which they refer, will be a sufficient apology for the increase of their number; more especially when it is considered, that the augmented number of plates, as well as the enlargement of the work, have occasioned a diminution of profit to the Proprietors. It would have been more their interest, as well as more gratifying to the Editor, to have compiled a Cyclopædia in fewer volumes, and to have contented themselves with a smaller number of plates; as in all probability the sale would have been greater, and the sum of money expended upon it would of course have been much less. The Editor must do the booksellers concerned in this Cyclopædia the justice to say, that they have consented to forego part of the possible profit that might have accrued from it for the sake of its reputation and utility.

CYCLOPÆDIA:

OR, A NEW

UNIVERSAL DICTIONARY

OF

ARTS and SCIENCES.

Acetic Acid

ACETIC ACID, in *Chemistry*, *Radical vinegar*, *Acide Acétique*, *Vinaigre radical*, *Vinaigre de Vénus*. If any quantity of crystallized acetite of copper (distilled verdigrise) be distilled in a glass retort, with a regulated heat, till at length the bottom of the vessel is nearly red hot, the equilibrium of the affinity between the component parts of the salt will be destroyed, and several new substances in consequence produced. The proportion of these on 1000 parts of the salt, according to an accurate analysis of Cit. Adet, will be 486 acetic acid, 312 brown oxyd of copper mixed with charcoal, 118 hydrogen and carbonic acid gas, and about 84 of the acetite of copper, will remain undecomposed. In order to be fully aware of what takes place in these changes, it is necessary to observe, that the crystallized acetite of copper contains hydrogen and oxygen forming the water of crystallization, hydrogen, carbon, and oxygen forming acetous

acid, and copper, with about 25 per cent. of oxygen. By the process of distillation, the acetous acid appears to be decomposed by the separation of part of its hydrocarbonous base, and at the same time the oxyd of copper is brought to a lower state of oxydation: part of the carbon becomes acidified at the expence of the copper, and, uniting with the hydrogen, forms hydrocarbonous gas; the remainder of the carbon is found in the retort, mixed with the oxyd of copper, and possesses the properties of a pyrophorus. Thus it seems that acetic acid differs from acetous, in a larger proportion of oxygen to the base, which is effected not by an addition of oxygen, but by a diminution of the base. Acetic acid may also be procured by distilling together acetite of lead, of soda, potash, or lime, with sulphuric acid; the product is however, in this case, contaminated by sulphureous acid gas; but this may be in part prevented, by

adding to the materials some black oxyd of manganese. M. Badollet proposes to obtain acetic acid, by distilling equal parts of sulphat of copper, and acetite of lead: the acid thus produced costs only a fourth of that which is formed from acetite of copper. In its general properties, acetic acid is very similar to acetous acid, yet differing from it in the following particulars.

The active acid qualities of this fluid bring it to a near resemblance with some of the mineral acids; it is corrosive, and intensely acid to the taste, exhales a pungent almost suffocating odour, and has nothing of the spirituous flavour of distilled vinegar: its specific gravity is 1.0626. With earthy and alkaline bases it unites readily, forming the genus of neutral and earthy acetats, the properties of which have been but very little examined. It dissolves copper, and certain other metals which are not soluble in acetous acid, and it is capable of partly decomposing and uniting with alcohol, forming acetic ETHER.

This acid is of some use in the laboratory, and is employed occasionally in medicine, as a stimulant application to the nostrils in fainting fits; for this purpose some acetite of potash is put into a smelling-bottle, and a little sulphuric acid is poured upon it. *Annales de Chimie*. xxvii. 299. xxviii. 113. Fourcroy, *Syst. des Connais. Chim.* viii. Gren's *Chem.* ii.

ACETITE OF POTASH. *Kali acetatum*, Lond. Pharm. *Lixiva acetata et Tartar. regenerat.* Edin. Pharm. *Acétite de Potasse. Terra foliata Tartari. Digestive salt of Silvius.*

This salt occurs native in the sap, and certain other vegetable juices, and also in the urine of some quadrupeds: it is prepared artificially by adding to pearlash, or carbonat of potash, distilled vinegar, till the liquor contains a slight excess of acid; if the salt is wanted in a solid state, evaporation in a glass or silver vessel must be had recourse to; when a pellicle appears on the surface, the process should go on at a very gentle temperature, till all the moisture is exhaled; there will remain a white micaceous salt, which must immediately, while warm, be put into a well-closed vial. The salt may also be obtained cheap and pure, by adding sulphat of potash to acetite of lime, evaporating to dryness in a water-bath, and dissolving out the acetite of potash by hot alcohol.

Acetite of potash has a lively penetrating odour, and a sharp taste; but leaving an alkaline impression on the palate: it crystallizes in needles and plates, the form of which has not been ascertained.

This salt has a strong affinity for water, deliquiating readily in the air: it requires 1.021 parts of this fluid at 50° Fahr. for its solution, and, while dissolving, absorbs caloric: from its hot saturated solution in alcohol, crystals may be obtained by cooling.

Of the alkalies and alkaline earths, barytes alone is capable of decomposing acetite of potash, setting at liberty the alkali, and forming with the acid acetite of barytes.

The sulphuric, nitric, muriatic, fluoric, phosphoric, oxalic, tartareous, arsenic, succinic and malic acids, are each capable of separating the acetous acid from its alkaline base: all the easily soluble sulphats, and several other neutral salts effect the same by double affinity.

Acetite of potash, subjected to dry distillation, yields hydrocarbonous gas, an ammoniacal liquor mixed with empyreumatic oil, sublimed crystals of carbonat, or acetite of ammonia, and there remains in the retort, charcoal, with potash, partly caustic, and partly carbonated. The appearance of ammonia in this process, is a circumstance well worthy of accurate investigation: it was first observed by Beaumé, and afterwards by Morveau, and seems likely to

throw much light on one of two very important questions, viz. Is azot a compound? Is ammonia one of the elements of potash? Ammonia consists of azot and hydrogen, but acetite of potash furnishes only oxygen, hydrogen, carbon, and potash; hence, it seems reasonable to suppose, either that these four substances contain the bases of azot, or that ammonia is one of the component parts of potash.

The above salt is applied to no use in the laboratory, or in the arts: it is an article of the *Materia Medica*, and possesses considerable diuretic qualities.

Beaumé, *Chim. Experim.* Fourcroy, *Connais. Chim.* Encyclop. Method. Art. Acète de Potasse. Gren's *Chemistry*.

ACETITE OF SODA. *Acétite de Soude. Terra foliata mineralis vel crystallizata.*

To any quantity of carbonated soda add distilled vinegar, leaving the liquor, however, still alkaline; evaporate gently to a pellicle, and by cooling, acetite of soda will be obtained in long striated prismatic crystals similar to those of sulphated soda, permanent in the air, soluble at a gentle temperature in their water of crystallization, and of a pungent bitterish taste.

Acetite of soda is easily soluble in water and alcohol, is decomposable with abstraction of the acid or alkaline base by potash, and the same substances as the preceding salt: when kept long in solution it is converted into carbonat of soda by decomposition of its acid; if subjected to dry distillation it yields hydrocarbonous gas, empyreumatic oil and acid, and there remains in the retort, charcoal and carbonated soda.

This salt is employed a little in France as a medicine—in this country is made no use of.

Beaumé, *Ch. Exp.*—Fourcroy, *Syst. des Conn. Chim.*—Encyclop. Method. art. Acétite de Soude—Gren's *Chem.*

ACETITE OF AMMONIA. *Acétite d'Ammoniaque.*—*Ammonia Acetata et Spiritus Mindereri*; Lond. et Edin. Pharm.

This is prepared in the liquid form by adding carbonated ammonia to distilled vinegar till saturation. On account of its great volatility, it is not very easy to obtain it in the crystalline form; the following method was successfully practiced by M. Delassone for this purpose: equal parts of chalk and sal-ammoniac were mixed well together, and put into a retort, upon which was poured half their weight of concentrated acetous acid; by a gentle heat a white vapour arose, which concreted in beautiful crystals in the receiver, and was acetite of ammonia. Another way of preparing this salt is by distilling equal parts of acetated lead (sugar of lead), and muriated ammonia (sal-ammoniac.)

This substance is very deliquescent—has a hot pungent flavour—is decomposed by alkalies, by most acids, and by double affinity in various ways; it is destroyed by fire, and spontaneously when in solution.

It is only employed in medicine, and is considered as a diaphoretic.

Beaumé, *Ch. Exp.*—Fourcroy, *Syst. des Connais. Chim.*—Encyclop. Method. art. Acète d'Ammonia.—Gren, ut supra.

ACETITE OF LIME. *Acétite de Chaux.*—*Salt of Chalk, Salt of Coral.*

This salt is readily procured, by adding distilled vinegar to chalk, marble, coral, oyster-shells, or any other substance that consists chiefly of calcareous carbonat; the carbonic acid is disengaged with effervescence, and by evaporating the solution to a pellicle, and allowing it to cool gradually, crystals of acetite of lime are deposited.

Calcareous acetite crystallizes in white slender silky filaments, permanent in the air; its taste is bitter, acerb, rather caustic; it is soluble with ease in water, and in small proportion

proportion by alcohol. Barytes, and the fixed alkalis decompose it, by union with its acid; the stronger acids do the same, by combining with its earthy base: most of the carbonates and sulphates decompose it by compound affinity: when in solution, it is destroyed spontaneously by decomposition of the acid, and deposits carbonate of lime: in dry distillation it yields hydrocarbonous gas, empyreumatic acid and oil, charcoal and calcareous carbonate.

It is still admitted into the foreign pharmacopœas as a sudorific and diuretic.

Beaumé, Ch. Exp.—Fourcroy, Syst. des Connaiss. Chim. Encyclop. Method. art. Acète Calcaire.—Gren, ut supra.

ACETITE OF BARYTES. *Acétite de Baryt.*

This salt is usually prepared by adding carbonate of barytes to distilled vinegar, in which case the acid is always in excess: when reduced by evaporation, to the consistence of a syrup, and allowed to cool gradually, it deposits a white opaque granular salt, and the sides of the vessel are covered with silky filaments of the same: a better way of procuring this substance, is by boiling for a few minutes the sulphuret of barytes in a slight excess of acetous acid, (vide ACETITE of Strontian) filtering the solution, and setting it to evaporate spontaneously; transparent crystals may thus be obtained in long slender prisms. The salt formed by either of these methods is permanent in the air, and decomposable by most of the mineral acids, the carbonated alkalis, and the sulphuric salts. Its only use is as a reagent, for ascertaining the presence of sulphuric acid in those cases where the muriate or nitrate of barytes might affect the results of the analysis.

Encyclop. Method. art. Acète Barotique.

ACETITE OF STRONTIAN. *Acétite de Strontian.*

To any quantity of warm distilled vinegar, add gradually sulphuret of strontian, as long as any effervescence is perceived; then boil the liquor for a few minutes, and filter; add afterwards, drop by drop, a solution of acetite of lead, (sugar of lead) as long as any precipitate takes place, then suffer the liquor to stand for a few hours, and finally separate it from the dark sediment by filtration. This salt has not as yet been the subject of experiment; its properties are, in all probability, very similar to those of the Acet. Baryt. It is not made any use of.

ACETITE OF MAGNESIA. *Acétite de Magnésie.*

This salt is prepared by saturating distilled vinegar with carbonated magnesia, then boiling the liquor to separate the remains of carbonic acid and filtering it, if turbid, to get rid of the excess of carbonated magnesia.

The taste of acetite of magnesia, is sweet, with a slight mixture of bitter: by evaporation, it is reduced to a viscous syrupy consistence, incapable of being crystallized; but by further concentration, and subsequent cooling, becomes solid, and deliquescent in the air: it is totally soluble in spirit

of wine, and from the ease with which it is decomposed, the affinity between its elements appears to be extremely weak. The alkalis, and the rest of the alkaline earths, most of the mineral, vegetable, and animal acids are capable of decomposing this salt by abstraction of its acid or earthy base. It is not made any use of.

Encyclop. Method. art. Acète Magnésien. Pearson's Table of Affinity.

ACETITE OF ALUMINE. *Acétite d'Alumine. Aluminous mordant* of the calico-printers.

Of all the acetous salts this is the most important, being absolutely essential to the improved state of the arts of DYEING and CALICO-PRINTING. It is not easy to prepare this salt directly, distilled vinegar, even when concentrated, having no perceptible action on clay; the fresh precipitated and washed earth of alum is indeed soluble by long digestion in a large excess of acetous acid; but the most economical and effectual way of producing the salt in question, is by means of the double affinities of common alum and sugar of lead. For this purpose, to a blood-warm solution of alum in rain-water, is first of all to be cautiously added a solution of pearl-ash, or any other sufficiently pure alkali, till the liquor is just upon the point of becoming turbid, in order to saturate the excess of acid in common alum; a cold saturated solution of acetite of lead (sugar of lead) in rain-water is then to be stirred in as long as any precipitation takes place: by standing a few hours, the sulphate of lead entirely subsides, and the supernatant clear liquor, containing acetite of alumine and potash, may be drawn off with a syphon. By washing the sediment with cold water a dilute solution of acetite of alumine is obtained, which may be used instead of water in dissolving alum for the next preparation of aluminous mordant.

Acetite of alumine thus prepared has an acetous strongly styptic taste: by gradual evaporation and cooling, it assumes the form of small needle-shaped crystals, which are exceedingly deliquescent: by a heat inferior to that of boiling water, the acid is almost wholly driven off. It is decomposed by magnesia, and by all the substances that decompose acetite of magnesia. Its use is almost wholly confined to the dyers and calico-printers.

Encyclop. Method. art. Acète Alumineux.

ACETITE OF GLYCINE. *Acétite de Glucine.*

This is an uncrystallizable salt, which by evaporation becomes of a gummy semiductile consistence; its taste is sweet, and very astringent, with a flavour of vinegar: its other properties have not been examined into; it is not applied to any use. B. la Grange, ii. 452.

For the metallic acetites, see the respective metals.

ACETIFICATION is used by some Chemists to denote the action or operation, by which vinegar is made. See Acetous FERMENTATION.

Acid

ACID, in *Chemistry*, is used in common language as a generic name for all those substances which impress the organs of taste with a sharp sour sensation. Since, however, there are certain bodies destitute of this property, which nevertheless are classed by all chemical writers as acids, this popular characteristic must be abandoned as essential, for one which is more comprehensive.

Newton's well known definition of an acid, "that which strongly attracts, and is strongly attracted," would have required notice only in the history of chemical opinions, if it had not been implicitly adopted by one of the ablest chemists of the present age, Cit. Guyton Morveau. (Dict. Method.

art. *acide*.) "Now if any one should ask me," says he "what is an acid, I reply, it is that which of all palpable substances is the most powerful solvent; that which acts on the greatest number of other bodies; that, as Newton has so well expressed it, which strongly attracts, and is strongly attracted." It is a greater fault for a definition to be too comprehensive than too circumscribed, and that which has been just quoted not only includes alkalies as well as acids, as indeed Morveau allows, but all the active chemical agents, such as water, alcohol, hydrogen, oxygen, &c. for they are all powerful solvents; act on a great number
bcr

her of other bodies, strongly attract, and are strongly attracted. In fact, there is no one property peculiar to the genus acid, and which belongs to each species, so that it is not possible to give a definition of the term: nevertheless, by combining together the general distinguishing qualities of acids, and noting at the same time the exceptions to these, a description may be produced more illustrative than the most laboured definition.

Previously to the consideration of the general properties of acids, it will be an advantage to give a sketch of the opinions held by the old chemists concerning their origin and mode of action, and to examine more at large the theory of Lavoisier upon the same subject.

When the mechanical system was in vogue, according to which the chemical action of bodies was explained by the supposed figure and size of their respective molecules, acids were supposed to be a genus of salts, composed of extremely small and sharp spicules, which readily penetrated into the minutest pores of the substances subjected to their action, and thus separated from each other their component parts; while, at the same time, the acid became neutralized by its points being sheathed in the pores of the body with which it was mixed. This explanation was, however, ably controverted by Boyle, and by Stahl in his work on salts; and, at length, together with other chemical phenomena, the solvent power of acids was arranged by Macquer and his contemporaries, under the general laws of elective attraction.

After a few of the acids were discovered, it was supposed by Paracelsus, and several chemists of his age, that there existed an universal saline element, or principle of acidity common to all acids, which therefore differed from each other rather in mode than essence. Becher, though he allowed the unity of the cause of acidity, yet affirmed it to be composed of water and vitrifiable earth, and therefore not entitled to rank as an element. Stahl, in his valuable researches into the existence of phlogiston, and the composition of salts, was induced to believe that the sulphuric acid, or as it was then called the vitriolic, was the original acid, of which all the rest were only modifications. A similar opinion was held by Sage and Landriani, except that the former supposed the phosphoric acid, and the latter the carbonic acid, to be the primary one. The discovery of dephlogisticated air, (oxygen gas) having been made by Priestley in 1774, a multitude of experiments were soon after instituted by the chemists of Europe on this interesting substance; and, in 1778, a memoir was presented to the royal academy of sciences at Paris, by Lavoisier, on the composition of the acid of sugar. In this, after having described the method of preparing the acid of sugar by means of nitrous acid, he concludes, that the conversion of nitrous acid into nitrous gas, is owing to the abstraction of part of its oxygen by the superior affinity of sugar for this substance, and that the sugar in consequence of its union with oxygen acquires the properties of an acid. Proceeding afterwards to generalize this inference, he maintains that oxygen is the universal acidifying element, and that by combining in certain proportions with combustible bases without decomposing them, it thereby converts them into peculiar acids. This doctrine, simple and elegant, and plausible as it was, did not however at first meet with general concurrence; but, in the course of the controversy, it gradually acquired, and merited new advocates from the accumulated testimonies of experiment in its confirmation.—The publication of Lavoisier's Elements of Chemistry, in 1789, contributed more than any thing else to settle the opinion of chemists upon

the subject; in this work he demonstrates that phosphorus and charcoal, and sulphur, being separately inflamed in oxygen gas, combine with its base, acquire an additional weight equivalent to that of the air consumed, and are converted into the phosphoric, carbonic, and sulphuric acids.

Besides the synthetical arguments above alluded to, the Lavoisierian theory is supported by an equal number of analytical experiments, in which most of the known acids are decomposed into oxygen, and one or more combustible bases. The most elegant specimen of both kinds of proof is furnished by the nitrous acid: if purified nitre, (nitrat of potash) previously deprived of its water of crystallization, be exposed in a silver retort to a low red heat, a large quantity of gas, consisting of oxygen and azot, in the proportion of about 80 of the former to 20 of the latter, will be given out, and pure potash will remain in the retort, whose weight together with that of the gases will be equivalent to that of the original nitre; the mixed gases are wholly destitute of acid properties, but by being forced into union by means of the electric spark, their volume is gradually diminished, and at length the whole is reduced to an acid liquor, possessing all the qualities of nitrous acid; if this and the potash remaining in the first process be mixed together, chemical union immediately ensues, and nitre is reproduced.

Three of the known acids are incapable of being decomposed by any method that we are at present acquainted with; it is therefore only from analogy that they are supposed to contain oxygen for their acidifying principle; this circumstance, however, is no peculiar objection to the theory of Lavoisier, for since all the decomposable acids may be resolved into oxygen and a simple or compound combustible base, it seems consistent with the principles of chemical philosophy to establish that as a general law, to which in the present state of our knowledge, there is not a single exception.

Substances, whose mutual affinity is considerable, may combine with each other in various proportions, and the resulting compounds will vary in their properties accordingly: this is the case with all the known acidifiable bases which in their lowest state of oxydation exhibit no acid properties whatever: nor is the development of an acid an evidence of the complete saturation of its base with oxygen, there being several acids capable of combining with additional quantities of oxygen, and thus acquiring new and more decided acid characters.—It is even supposed that some bases may be oxygenated in three different degrees, preserving in each the essential qualities of acids: hence results an important arrangement of acids according as they are oxygenated in the first, second or third degree. The reformed chemical nomenclature on the principles of Lavoisier and Berthollet, has ingeniously distinguished these states by the terminations *ous* and *ic*, and the prefix *oxy* (for oxygenated); thus sulphur, at the lowest state of oxygenation in which it acquires acid properties, is called *sulphureous acid*; when still further oxygenated it becomes *sulphuric acid*; thus also, muriatic acid, when raised to the third degree of oxygenation, becomes *oxy-muriatic acid*.

The old chemists divided acids into mineral, vegetable, and animal, according to their supposed origin; this, however, is not only an inconvenient, but an incorrect method of arrangement, as many of these bodies are found in all the three natural kingdoms. Upon the whole, perhaps, the best way of arranging them is the following:

		States of Oxygenation.		
		Bases.	1st.	2d.
With simple radicals.	<i>Sulphur</i>	-	Sulphureous	Sulphuric
	<i>Azot</i>	-	Nitrous	Nitric
	<i>Phosphorus</i>	-	Phosphoreous	Phosphoric
	<i>Carbon</i>	-	-	Carbonic
	<i>Arsenic</i>	-	Arsenious	Arsenic
	<i>Molybdena</i>	-	-	Molybdic
With double radicals.	<i>Chrome</i>	-	-	Chromic
	{ <i>Carbon and Hydrogen in different proportions.</i>	{	Acetous	Acetic
				Tartaric
				Citric
				Oxalic
				Malic
				Gallic
With triple radicals.	{ <i>Carbon, Hydrogen, and Azot.</i>	{		Benzoic
				Succinic
With unknown radicals.	{	{		Saccharic
				Lactic
				Formic
				Sebacic?
	{	{		Prussic
				Lithic
	{	{	Muriatic	Oxymuriatic
			Fluoric	
			Boracic	

The chemists of the last century seem to have been acquainted only with the three mineral acids, as they are called, viz. the sulphuric, nitric, and muriatic, and with the acetous acid or vinegar: the accuracy and industry of the moderns have increased the number of species to twenty-nine; how many more may be hereafter added to the list it is impossible to ascertain. Without adverting to the possibility of discovering new acidifiable bases, it is by no means improbable, however, that many of the simple combustible bodies as the metals, or the compound ones as phosphorated hydrogen, sulphurated hydrogen, the metallic phosphurets, &c. may be so far saturated with oxygen, as to become peculiar acids.

The characteristic properties of acids, *i. e.* the peculiar laws and effects of their action on other chemical sub-

stances, yet remain to be mentioned.

1. When taken into the mouth they occasion a sour taste. The oxymuriatic acid alone is destitute of this property; the rest possess it in a greater or less degree according to their liquid or solid form, and the energy with which they act on the animal fibre, from the corrosive and intensely sour sulphuric acid, to the boracic, whose taste can scarcely be perceived.

2. They change native vegetable blues to red.

Indigo is not turned red by any acid, nor does turnesol paper yield to some of the weakest ones, but both these pigments are artificial: the sulphureous and oxymuriatic acid discharge entirely the native vegetable blues, not however before having changed them to red.

3. They have a stronger affinity for alkalies than these have for any other substance. Therefore, all the soluble combinations of alkalies with metallic oxyds, with earths, with sulphur, &c. are decomposed by any acid.

4. They combine with earths, with alkalies, and with metallic oxyds, forming the numerous and very important classes of earthy, neutral, and metallic salts, most of which are susceptible of crystallization.

5. The property of incombustibility has been generally attributed to acids as a characteristic, but certainly very erroneously. The most incombustible of the acids are no more so than the fixed alkalies, the earths, and the perfect metallic oxyds; and all the acids with two or three radicals, and those with simple radicals in the first state of oxygenation, are, strictly speaking, combustible, that is, they unite at a certain temperature with oxygen gas, during which combination heat, and in some cases light also, are extricated.

The medical effects of acids are considerable, and vary according to their degree of concentration; the most active, when pure, or nearly so, are used externally as caustics and escharotics, and as powerful stimulants in some cases of palsy: if largely diluted with water, they may be safely employed internally in fevers, inflammations, and hemorrhages, as refrigerants and astringents.

For the particular acids, see them under their specific names.

Encycloped. Method. art. Acide.—Lavoisier's Elements of Chemistry.—Priestley on Air, vol. ii.—Fourcroy, Systeme des Connoiss. Chimiq. vol. ii.—Macquer's Chem. Dict. art. Acid. Cullen Mat. Med. vol. ii.

Aerostation

AEROSTATION, formed of *αἰρ*, and *στάσις*, of *ἄνω, I weigh*, the science of weights, in its primary and proper sense, denotes the science of weights, suspended in the air; but in the modern application of the term, it signifies the art of navigation through the air, both in the principles and the practice of it. Hence also the machines, which are employed for this purpose, are called *aerostats*, or *aerostatic machines*; and, on account of their round figure, *air-balloons*. The *aeronaut*, formed of *αἰρ* and *ναύτης, sailor*, is the person who navigates through the air by means of such machines.

AEROSTATION, *principles of*. The fundamental principles of this art have been long and generally known; although the application of them to practice seems to be altogether a modern discovery. They are particularly illustrated in this Dictionary under the articles *Weight of Air*, *Elasticity of Air*, and *Specific Gravity*.

It will be sufficient, therefore, to observe in this place, that any body, which is specifically, or bulk for bulk, lighter than the atmospheric air encompassing the earth, will be buoyed up by it, and ascend; but as the density of the ATMOSPHERE decreases, on account of the diminished pressure of the superincumbent air, and the elastic property which it possesses, at different elevations above the earth, this body can rise only to a height in which the surrounding air will be of the same specific gravity with itself. In this situation it will either float, or be driven in the direction of the wind or current of air, to which it is exposed. An air-balloon is a body of this kind, the whole mass of which, including its covering and contents, and the several weights annexed to it, is of less specific gravity than that of the air in which it rises.

Heat is well known to rarefy and expand, and consequently to lessen the specific gravity of the air to which it is applied; and the diminution of its weight is proportional to the heat. To the observations that occur under *Elasticity of Air* to this purpose, we shall here add, that one

degree of heat, according to the scale of Fahrenheit's thermometer, seems to expand the air about one four hundredth part; and about 400, or rather 435, degrees of heat, will just double the bulk of a quantity of air. If, therefore, the air inclosed in any kind of covering be heated, and consequently dilated, to such a degree, as that the excess of the weight of an equal bulk of common air above the weight of the heated air, is greater than the weight of the covering and its appendages, this whole mass will ascend in the atmosphere, till, by the cooling and condensation of the included air, or the diminished density of the surrounding air, it becomes of the same specific gravity with the air in which it floats; and without renewed heat, it will gradually descend.

If, instead of heating common air inclosed in any covering, and thus diminishing its weight, the covering be filled with an elastic fluid, lighter than atmospheric air; so that the excess of the weight of an equal bulk of the latter above that of the inclosed elastic fluid be greater than the weight of the covering and its appendages, the whole mass will in this case ascend in the atmosphere, and continue to rise till it attains a height at which the surrounding air is of the same specific gravity with itself. Inflammable air is a fluid of this kind. For the knowledge of many of its properties, we are indebted to Mr. Henry Cavendish: who discovered, that if common air is eight hundred times lighter than water, inflammable air is seven times lighter than common air; but if common air is eight hundred and fifty times lighter than water, then inflammable air is 10,8 times lighter than common air. See Phil. Transf. vol. lvi. art. 19. and *Inflammable Air or Hydrogen*.

The construction of air-balloons depends upon the principles above stated; and they are of two kinds, as one or the other of the preceding methods of preparing them is adopted.

AEROSTATION, *history of*. In the various schemes that have

have been proposed for navigating through the air, some have had recourse to artificial wings; which, being constructed like those of birds, and annexed to the human body, might bear it up, and by their motion, produced either by mechanical springs, or muscular exertion, effect its progress in any direction at pleasure. This is one of the methods of artificial flying suggested by bishop Wilkins, in the seventh chapter of his *Dædalus, or Treatise on Mechanical Motions*; but the success of it is doubtful, and experiments made in this way have been few and unsatisfactory. Borelli (*De Motu Animalium*, cap. 22. prop. 193 and 204, p. 196 and 208, ed. 1710), having compared the power of the muscles which act on the wings of a bird with that of the muscles of the breast and arms of a man, finds the latter altogether insufficient to produce, by means of any wings, that motion against the air, which is necessary to raise a man in the atmosphere.

Others, with greater probability of success, have proposed to attach the human body to some mass, which being lighter than air, might raise itself and the annexed weight into the regions of that element. This method has actually succeeded; though Borelli (*ubi supra*), as well as Leibnitz, denied the possibility of a man's flying by any of the means with which they were acquainted.

It is needless to recite any of the accounts relating to this subject, which have been transmitted to us by the ancients. Most, if not all of them, are fabulous. An ingenious writer, in a work cited at the close of this article, has given us the result of his enquiries into the records of antiquity; and he informs us, that the earliest account of any thing relating to flying, which has the appearance of authenticity, is that of the wooden pigeon, constructed by Archytas in the fourth century, before the Christian æra, and of which Aulus Gellius (*Noctes Atticæ*, lib. x. cap. 12.) relates, that it could fly by means of mechanical powers, and by an inclosed spirit. This spirit, or aura, our author apprehends, was nothing more than a sort of animation, which the machine appeared to be possessed of, in consequence of its extraordinary mechanism. Aerostation was, therefore, a subject either altogether unknown, or very imperfectly understood among the ancients; unless we suppose it to be one of those arts, of which the records are lost. In later times, the schemes which have been proposed by ingenious men seem to have terminated in speculation. The reader will find a brief account of some of them under the articles *ATMOSPHERE* and *Artificial Flying*, and a more comprehensive history of the projects and achievements of different persons, in the work cited below. Upon the whole it appears, that the art of traversing the air is an invention of our own time; and the whole history of it is comprehended within a very short period.

Soon after Mr. Cavendish's discovery of the specific gravity of inflammable air, it occurred to the ingenious Dr. Black of Edinburgh, that if a bladder, sufficiently light and thin, were filled with this air, it would form a mass lighter than the same bulk of atmospheric air, and rise in it. This thought was suggested in his lectures in 1767 or 1768; and he proposed, by means of the allantois of a calf, to try the experiment. Other employments, however, prevented the execution of his design. The possibility of constructing a vessel, which, when filled with inflammable air, would ascend in the atmosphere, had occurred also to Mr. Cavallo about the same time; and to him belongs the honour of having first made experiments on this subject, in the beginning of the year 1782, of which an account was read to the Royal Society, on the 20th of

June in that year. He tried bladders; but the thinnest of these, however scraped and cleaned, were too heavy. In using China paper, he found that the inflammable air passed through its pores, like water through a sieve; and having failed of success by blowing this air into a thick solution of gum, thick varnishes, and oil paint, he was under a necessity of being satisfied with soap-balls, which, being inflated with inflammable air, by dipping the end of a small glass tube, connected with a bladder containing the air, into a thick solution of soap, and gently compressing the bladder, ascended rapidly in the atmosphere; and these were the first sort of inflammable air-balloons that were ever made.

For balloons formed on a larger scale, and on the principle of rarefied air, we must direct our attention to France; where the two brothers, Stephen and Joseph Montgolfier, paper-manufacturers at Annonay, about 36 miles from Lyons, distinguished themselves by exhibiting the first of those aerostatic machines, which have since excited so much attention and astonishment. The first idea of such a machine was suggested to them by the natural ascent of the smoke and clouds in the atmosphere; and the first experiment was made at Avignon by Stephen, the eldest of the two brothers, towards the middle of November, 1782. Having prepared a bag of fine silk, in the shape of a parallelepipedon, and in capacity about forty cubic feet, he applied to its aperture burning paper, which rarefied the air, and thus formed a kind of cloud in the bag; and when it became sufficiently expanded, it ascended rapidly to the ceiling. Soon afterwards the experiment was repeated by the two brothers at Annonay, in the open air, when the machine ascended to the height of about seventy feet. Encouraged by their success, they constructed a machine, the capacity of which was about 650 cubic feet; which, in the experiment, broke the ropes that confined it, and after ascending rapidly to the height of about 600 feet, fell on the adjoining ground. With another machine, 35 feet in diameter, they repeated the experiment in April, 1783; when breaking loose from its confinement, it rose to the height of above 1000 feet, and being carried by the wind, it fell at the distance of about three quarters of a mile from the place where it ascended. The capacity of this machine was equal to about 23,430 cubic feet; and when inflated, it measured 117 English feet in circumference. The covering of it was formed of linen, lined with paper; its shape was nearly spherical; and its aperture was fixed to a wooden frame about 16 feet in surface. When filled with vapour, which was conjectured to be about half as heavy as common air, it was capable of lifting up about 490 pounds, besides its own weight, which, together with that of the wooden frame, was equal to 500 pounds. With this machine the next experiment was performed at Annonay, on the 5th of June, 1783, before a great multitude of spectators. The flaccid bag was suspended on a pole 35 feet high; straw and chopped wool were burnt under the opening at the bottom; the vapour, or rather smoke, soon inflated the bag, so as to distend it in all its parts; and this immense mass ascended in the air with such a velocity, that in less than 10 minutes it reached the height of about 6000 feet. A breeze carried it in an horizontal direction to the distance of 7668 feet; and it then fell gently on the ground. Mr. Montgolfier attributed the ascent of the machine, not to the rarefaction of the heated air, which is the true cause, but to a certain gas or æreiform fluid, specifically lighter than common air, which was supposed to be disengaged from burning substances, and which

has been commonly called *Montgolfier's gas*, as balloons of this kind have been denominated *Montgolfiers*.

As soon as the news of this experiment reached Paris, the philosophers of the city, conceiving that a new sort of gas, half as heavy as common air, had been discovered by Messrs. Montgolfier, and knowing that the weight of inflammable air was not more than the eighth or tenth part of the weight of common air, justly concluded that inflammable air would answer the purpose of this experiment better than the gas of Montgolfier, and resolved to make trial of it. A subscription was opened by M. Faujas de St. Fond towards defraying the expense of the experiment. A sufficient sum of money having been soon raised, Messrs. Roberts were appointed to construct the machine; and M. Charles, professor of experimental philosophy, to superintend the work. After surmounting many difficulties in obtaining a sufficient quantity of inflammable air, and finding a substance light enough for the covering, they at length constructed a globe of lutestring, which was rendered impervious to the inclosed air by a varnish of elastic gum or *caoutchouc*, dissolved in some kind of spirit or essential oil. The diameter of this globe, which from its shape was denominated a balloon, was about thirteen feet, and it had only one aperture, like a bladder, to which a stop-cock was adapted: its weight, when empty, together with that of the stop-cock, was 25 pounds. On the 23d of August, 1783, they began to fill the globe with inflammable air; but this, being their first attempt, was attended with many hindrances and disappointments. At last, however, it was prepared for exhibition; and on the 27th it was carried to the Champ de Mars, where, being disengaged from the cords that held it down, it rose before a prodigious concourse of people, in less than two minutes, to the height of 3123 feet. It then entered a cloud, but soon appeared again; and at last it was lost among other clouds. This balloon, after having floated about three quarters of an hour, fell in a field about fifteen miles distant from the place of ascent; where, as we may naturally imagine, it occasioned much astonishment to the peasants. Its fall was owing to a rent, occasioned by the expansion of the inflammable air in that rare part of the atmosphere to which it ascended. When the balloon went up, its specific gravity was 35 pounds less than that of common air.

In consequence of this brilliant experiment, many balloons were made on a small scale; gold-beaters skin was used for the covering; and their size was from 9 to 18 inches in diameter.

Mr. Montgolfier repeated an experiment with a machine of his construction before the commissaries of the Academy of Sciences on the 11th and 12th of September. This machine was 74 feet high, and about 43 feet in diameter. When distended, it appeared spheroidal. It was made of canvas, covered with paper, both within and without; and it weighed 1000 pounds.

The operation of filling it with rarefied air, produced by means of the combustion of 50 pounds of dry straw, and 12 pounds of chopped wool, was performed in about nine minutes; and its force of ascension, when inflated, was so great that it raised eight men who held it some feet from the ground. This machine was so much damaged by the rain, that it was found necessary to prepare another for exhibition before the king and royal family on the 19th. This new machine consisted of cloth, made of linen and cotton thread, and was painted with water-colours both within and without. Its height was near 60 feet, and its diameter about 43 feet. Having made the necessary preparations for in-

flating it, the operation was begun about one o'clock on the 19th of September, before the king and queen, the court, and all the Parisians who could procure a conveyance to Versailles. In eleven minutes it was sufficiently distended, and the ropes being cut, it ascended, bearing up with it a wicker cage, in which were a sheep, a cock, and a duck. Its power of ascension, or the weight by which it was lighter than an equal bulk of common air, allowing for the cage and animals, was 696 pounds.

This balloon rose to the height of about 1440 feet; and being driven by the wind, it descended gradually and fell gently into a wood, at the distance of 10,200 feet from Versailles. After remaining in the atmosphere eight minutes, the animals in the cage were safely landed. The sheep was found feeding; the cock had received some hurt on one of his wings, probably from a kick of the sheep; the duck was perfectly well.

The success of this experiment induced M. Pilatre de Rozier, with a philosophical intrepidity which will be recorded with applause in the history of aerostation, to offer himself as the first adventurer in this aerial navigation. Mr. Montgolfier constructed a new machine for this purpose in a garden in the Fauxbourg St. Antoine. Its shape was oval; its diameter being about 48 feet, and its height about 74 feet. To the aperture at the bottom was annexed a wicker gallery about three feet broad, with a ballustrade about three feet high. From the middle of the aperture was suspended by chains, which came down from the sides of the machine, an iron grate or brazier, in which a fire was lighted for inflating the machine; and port-holes were opened in the gallery, towards the aperture, through which any person, who might venture to ascend, might feed the fire on the grate with fuel, and regulate the dilatation of the inclosed air of the machine at pleasure. The weight of this aerostat was upwards of 1600 pounds. On the 15th of October, the fire being lighted and the machine inflated, M. P. de Rozier placed himself in the gallery, and ascended, to the astonishment of a multitude of spectators, to the height of 84 feet from the ground, and there kept the machine afloat during 4' 25", by repeatedly throwing straw and wool upon the fire: the machine then descended gradually and gently, through a medium of increasing density, to the ground; and the intrepid adventurer assured the spectators that he had not experienced the least inconvenience in this aerial excursion. This experiment was repeated on the 17th, and on the 19th, when M. P. de Rozier, in his descent, and in order to avoid danger by reascending, evinced to a multitude of observers, that the machine may be made to ascend and descend at the pleasure of the aeronaut, by merely increasing or diminishing the fire in the grate. The balloon having been hauled down, M. Giraud de Villette placed himself in the gallery opposite to M. Rozier; and being suffered to ascend, it hovered for about nine minutes over Paris in the sight of all its inhabitants at the height of about 330 feet. In another experiment the marquis of Arlandes ascended with M. Rozier much in the same manner. In consequence of the report of the preceding experiment, signed by the commissaries of the Academy of Sciences, it was ordered that the annual prize of 600 livres should be given to Messrs. Montgolfier for the year 1783. In the experiments above recited the machine was secured by ropes: but they were soon succeeded by unconfined aerial navigation. Accordingly the balloon of 74 feet in height, above mentioned, was removed to La Muette, a royal palace in the Bois de Boulogne: and all things being ready, on the 21st of November M. P. de

Rozier and the marquis d'Arlandes took their respective posts in the gallery, and at 54 minutes after one the machine was absolutely abandoned to the element, and ascended calmly and majestically in the atmosphere. The aeronauts, having reached the height of about 280 feet, waved their hats to the astonished multitude: but they soon rose too high to be distinguished, and are thought to have soared to an elevation of above 3000 feet. They were at first driven by a north-west wind horizontally over the river Seine and over Paris, taking care to clear the steeples and high buildings by increasing the fire; and in rising met with a current of air, which carried them southward. Having passed the Boulevard, and desisting from supplying the fire with fuel, they descended very gently in a field beyond the new Boulevard, about 5000 yards distant from the palace de la Muette. They were in the air about 25 minutes. The weight of the whole apparatus, including that of the two travellers, was between 1600 and 1700 pounds.

Notwithstanding the rapid progress of aerostation in France, we have no authentic account of any aerostatic experiments performed in other countries till about the close of the year 1783. The first experiment of this kind, publicly exhibited in our own country, was performed in London on the 25th of November, by count Zambecari, an ingenious Italian, with a balloon of oil silk, 10 feet in diameter, and weighing 11 pounds. It was gilt, in order to render it more beautiful and more impermeable to the inflammable air. This balloon, three-fourths of which were filled with inflammable air, was launched from the Artillery-ground, in the presence of a vast concourse of spectators, at one o'clock in the afternoon, and at half past three was taken up near Petworth, in Sussex, 48 miles distant from London; so that it travelled at the rate of near 20 miles an hour. Its descent was occasioned by a rent, which must have been the effect of the rarefaction of the inflammable air, when the balloon ascended to the rarer part of the atmosphere.

The Parisian philosophers having concerted and executed the first aerial voyage with a balloon inflated by heated air, determined to attempt a similar voyage with a balloon filled with inflammable air, which seemed to be preferable to dilated air in every respect, the expence attending it excepted. A subscription was opened to defray the charges, which were estimated at about ten thousand livres; and the balloon was constructed by Messrs. Roberts, of gores of silk, varnished with a solution of elastic gum. Its form was spherical, and it measured $27\frac{1}{2}$ feet in diameter. The upper hemisphere was covered by a net, which was fastened to the hoop encircling its middle, and called its equator. To this equator was suspended by ropes a car or boat, covered with painted linen and beautifully ornamented, which swung a few feet below the balloon. In order to prevent the bursting of the machine by the expansion of the inflammable air in a rarefied medium, it was furnished with a valve, which might be opened by means of a string annexed to it, for the discharge of part of the internal air without admitting the external to enter. To this balloon was likewise annexed a long pipe through which it was filled. The apparatus for filling it consisted of several casks placed round a large tub of water, each of which had a long tin tube, terminating under a vessel or funnel, that was inverted into the water of the tub. A tube proceeding from this funnel, communicated with the balloon, which stood just over it. Iron filings and diluted vitriolic acid were put into the casks; and the inflammable air, produced from these materials, passed through the tin tubes, through the water of the tub, and through the funnel of the balloon. The car was ballasted with sand-bags; so that by

letting some of the air escape through the valve they might descend, and by discharging some of their ballast ascend. The specific gravity of the inflammable air, with which the balloon was filled, was to that of common air nearly as 1 to $5\frac{1}{4}$, and the balloon's power of ascension, when filled for the experiment and when actually ascending, was twenty pounds. The weight of the balloon and of its various appendages was $604\frac{1}{2}$ pounds, and therefore the weight sustained by the inflammable air was $624\frac{1}{2}$ pounds: and if from the weight of the common air displaced, which was found to be $771\frac{1}{2}$ pounds, the former be subtracted, there will remain 147 pounds for the real weight of the inflammable air contained in the balloon.

The 1st of December was fixed upon for the display of this grand experiment; and every precaution was made for conducting it with advantage. The garden of the Thuilleries was the scene of operation; and it was crowded and encompassed with an innumerable multitude of observers. Signals were given by the firing of cannon, waving of pendants, &c. A small *Montgolfier* was launched for shewing the direction of the wind, and for the amusement of the people, previously to the general display. At three quarters after one o'clock, M. Charles and one of the Roberts, having seated themselves in the boat attached to the balloon, and furnished with proper instruments, provisions, and cloathing, left the ground, and ascended with a moderately accelerated velocity to the height of about 600 yards; the surrounding multitude standing silent with fear and amazement. At this height the aerial navigators made signals of their safety. When they went up, the thermometer, according to Fahrenheit's scale, stood at 59° ; and the barometer at 30, 18 inches. At the height to which they ascended the barometer stood at 27 inches, whence they deduced their elevation to be nearly 600 yards. During the rest of the voyage the quicksilver in the barometer was generally between 27 and 27, 65 inches, rising and falling as part of the ballast was thrown out or some of the inflammable air escaped from the balloon. The thermometer generally stood between 53 and 57° . Soon after their ascent, they remained stationary for some time: they then moved horizontally in the direction of N. N. W. and having crossed the Seine, and passed over several towns and villages, to the great astonishment of the inhabitants, they descended in a field about 27 miles distant from Paris at a quarter past three o'clock; so that they had travelled at the rate of about fifteen miles an hour, without feeling the least inconvenience. The balloon still containing a considerable quantity of inflammable air, M. Charles re-ascended alone. In ten minutes he thought himself at the elevation of about 1500 toises. The globe, being now in a rarefied medium, swelled considerably; but when some of the inflammable air was discharged, it rose still higher. The barometer, which at his departure stood at 28 inches four lines, had now fallen to 18 inches ten lines. The thermometer, from about 47° of Fahrenheit's scale, had sunk to 21° . From these data the elevation of the globe was estimated at 1524 toises, or about 3,100 yards. M. de Meunier supposes that he ascended to the height of at least 3500 yards. He continued in the air about 33 minutes, and by occasionally pulling the string of the upper valve, and thus letting out the gas, he descended about three miles from the place of his ascent. All the inconvenience he experienced in his elevation was a dry sharp cold, with a pain in one of his ears and a part of his face, which he ascribed to the dilatation of the internal air. The small balloon, launched by M. Montgolfier, was found to have moved in a direction opposite to that of the aeronauts; whence it is inferred,

that there were two currents of air at different heights above the earth.

In the month of December of this year, several experiments with balloons were made at Philadelphia, in America, by Messrs. Rittenhouse and Hopkins. They contrived to connect several small balloons together, and thus they enabled a man to ascend to the height of 100 feet, and to float to a considerable distance. But fear induced him to cut open the balloons, and thus to descend. Small balloons were at this time very common, both in France and England.

In January 1784, Mr. J. Montgolfier, accompanied by six other persons, ascended at Lyons, with a large rarefied air-balloon, 131 feet high, and 104 feet diameter, to the height of about 1000 yards. This was the largest machine that had hitherto been made. It was formed of a double covering of linen, with three layers of paper between, and strengthened with strings and ribbons. It contained about 540,000 cubic feet of igneous gas; and its weight, including the gallery and passengers, was 1600 pounds. After remaining in the air about fifteen minutes, a rent in the machine occasioned its fall: and when it came within about 600 feet of the ground, it descended with a degree of celerity which very much alarmed the spectators; but they all landed without injury.

On the 22d of February an inflammable air-balloon about five feet in diameter, was launched from Sandwich in Kent, which, travelling at the rate of about 30 miles an hour, crossed the English Channel, and descended in a field about nine miles from Lisle, in French Flanders.

The first person in Italy, who was at the expence of constructing an aerostatic machine for making an aerial voyage, was the chevalier Paul Andreani of Milan: his machine was spherical, about 68 feet in diameter, and formed upon the principle of those of Montgolfier. The chevalier, and two brothers of the name of Gerli, who had assisted in the construction of it, ascended, on the 25th of February, to the height of about 1200 feet; and they remained in the atmosphere about twenty minutes.

From the calculations made respecting the capacity of this machine, it appears, that the included air was not rarefied above one-third, or that the included warm air was not less than two-thirds of that which would have filled the machine, when of the same temperature with the external air; and this is the utmost degree of rarefaction that can be reasonably expected in balloons of this kind.

The next aerial voyage was performed by M. Jean Pierre Blanchard, who had for several years been employed, though without success, in attempts of flying by mechanical contrivances. This voyage was performed in March 1784, with a balloon 27 feet in diameter, to which a boat was suspended, with two wings and a rudder annexed to the boat, and a large umbrella or parachute spread horizontally between the boat and the balloon, designed to check the fall provided that the balloon should burst. The greatest altitude to which Mr. Blanchard ascended from the Champ de Mars at Paris, is supposed to be 9591 feet; and it appears from his own acknowledgment that the wings and rudder of his boat had little, if any, power in guiding the balloon from the direction of the wind. He was in the air an hour and a quarter, and descended at Billancourt, near Seve, after having experienced heat, cold, hunger, and an excessive drowsiness.

Aerostatic experiments and aerial voyages became so frequent in the course of the year 1784, that the limits of this article will not allow our particularly recording them. We

shall, therefore, merely mention those which were attended with any peculiar circumstances. Messrs. de Morveau and Bertrand ascended from Dijon in April, to the height of about 13000 feet, with an inflammable air balloon; the thermometer was observed to stand at 25 degrees. They were in the air during one hour and 25 minutes, and went to the distance of about 18 miles. Their ears were affected in the manner described by Mr. Charles. The clouds floated beneath them, and secluded them from the earth: and they jointly repeated the motto inscribed on their aerostat:—"Surgit nunc gallus ad æthera."

In May, four ladies and two gentlemen ascended with a Montgolfier at Paris above the highest buildings; the machine was confined by ropes. It was 74 feet high, and 72 in diameter.

In a second voyage performed by Mr. Blanchard from Rouen, in May, it was observed, that his wings and oars could not carry him in any other direction than that of the wind. The mercury in the barometer descended as low as 20.57 inches; but on the earth, before he ascended, it stood at 30.16 inches.

At Lyons, on the 4th of June, M. Fleurant and Madame Thible, the first lady that made an aerial voyage, ascended in the presence of Gustavus king of Sweden to the height of 8500 feet, and floated to the distance of about two miles in 45 minutes.

A balloon, 32½ feet in diameter, filled with inflammable air, extracted from zinc, was raised at Nantes on the 14th of June with two persons, viz. M. Coustard de Maffi and M. Mouchet; which ascended to a great height, and in 58 minutes travelled to the distance of 27 miles.

On the 23d of June a large aerostat, on the principle of rarefied air, 91½ feet high and 79 feet in diameter, was elevated by Montgolfier at Versailles, in the presence of the royal family and the king of Sweden. M. Pilatre de Rozier and M. Proust, ascended with it, and continued for 28 minutes at the height of 11732 feet and observed the clouds below them, that reflected to the region which they occupied the rays of the sun; the temperature of the air being 5° below the freezing point; and in three quarters of an hour they travelled to the distance of 36 miles. In consequence of this experiment the king granted to M. Rozier a pension of 2000 livres.

On the 15th of July the duke of Chartres, the two brothers Roberts, and another person, ascended with an inflammable air-balloon of an oblong form, 55½ feet long and 34 feet in diameter, from the Park of St. Cloud: the machine remained in the atmosphere about 45 minutes. This machine contained an interior small balloon, filled with common air, by which means it was proposed to make it ascend or descend without any loss of inflammable air or ballast. The boat was furnished with a helm and oars, intended for guiding it. At the place of departure the barometer stood at 30.12 inches. Three minutes after ascending, the balloon was lost in the clouds and involved in a dense vapour. An agitation of the air, resembling a whirlwind, alarmed the aerial voyagers, and occasioned several shocks, which prevented their using any of the instruments and contrivances prepared for the direction of the balloon. Other circumstances concurred to increase their danger; and when the mercury, standing in the barometer at 24.36 inches, indicated their height to be about 5100 feet, they found it necessary to make holes in the bottom for discharging the inflammable air: and having made a rent of between seven and eight feet, they descended very rapidly, and at last came safely to the ground.

On the 18th of July M. Blanchard, accompanied by a

Mr. Eoby, made his third aerial voyage with the same inflammable air-balloon, at Rouen; and ascended so high as to make the mercury in the barometer fall 4,76 inches, and the thermometer 40°. In two hours and a quarter they floated 45 miles, or at the rate of twenty miles an hour. In this voyage Mr. Blanchard conceived, that by agitating the wings of his boat he could not only ascend and descend, but move sideways against the wind; but subsequent trials do not seem to have established this fact. The machine retained its air during the night, and several ladies amused themselves the next day, by ascending with it to the height of 80 feet, the length of the ropes to which it was attached.

In the course of this summer two persons, one in Spain, and another in America, were in danger of losing their lives by ascending with rarefied air-machines. The former was scorched by the machine's taking fire, and so hurt by his fall, that his life was long despaired of; and the latter was wafted against the wall of a house, and so entangled, that he fell from the height of about twenty feet, and the machine took fire, and was consumed.

In the month of August, the Abbé Carnus, professor of philosophy, and M. Louchet, professor of belles lettres, ascended at Rodez, a town of Guienne in France, with an aerostatic machine of 57 feet in diameter. The air was calm, and the machine did not travel farther than about 14,900 yards in 46 minutes; and the height to which it ascended was 3920 yards above the level of the town. The thermometer was 34 degrees lower than it was at the earth when they ascended. On examining the air in one of two bottles, which they had filled at their highest elevation, they found that it contained a quarter less air than if it had been filled at about the level of the sea; and the air, tried by the test of nitrous air, was found more pure than that near the surface of the earth.

The first aerial voyage in England was performed in London, on the 15th of September, by Vincent Lunardi, a native of Italy. His balloon was made of oiled silk, painted in alternate stripes of blue and red. Its diameter was 33 feet. From a net which went over about two-thirds of the balloon, descended 45 cords to a hoop hanging below the balloon, and to which the gallery was attached. The balloon had no valve; and its neck, which terminated in the form of a pear, was the aperture through which the inflammable air was introduced, and through which it might be let out. The air for filling the balloon was produced from zinc by means of diluted vitriolic acid. Mr. Lunardi departed from the Artillery-ground at two o'clock; and with him were a dog, a cat, and a pigeon. After throwing out some sand to clear the houses, he ascended to a great height. The direction of his motion at first was north-west by west; but as the balloon rose higher, it fell into another current of air, which carried it nearly north. About half after three he descended very near the ground, and landed the cat, which was almost dead with cold: then rising, he prosecuted his voyage. He ascribes his descent to the action of an oar; but as he was under the necessity of throwing out ballast in order to re-ascend, his descent was more probably occasioned by the loss of inflammable air. At ten minutes past four he descended on a meadow near Ware in Hertfordshire. The only philosophical instrument which he carried with him was a thermometer, which in the course of his voyage stood as low as 29°, and he observed that the drops of water which collected round the balloon were frozen.

The longest and the most interesting voyage, which was performed about this time, was that of Messrs. Roberts and

M. Collin Hullin at Paris, on the 19th of September. Their aerostat was filled with inflammable air. Its diameter was 27½ feet, and its length 46½ feet, and it was made to float with its longest part parallel to the horizon, with a boat of nearly 17 feet long attached to a net that went over it as far as its middle. To the boat were annexed wings or oars, in the form of an umbrella. At 12 o'clock they ascended with 450 pounds of ballast, and after various manœuvres descended at 40 minutes past six o'clock near Arras, in Artois, having still 200 pounds of their ballast remaining in the boat. Having risen about 1400 feet, they perceived stormy clouds which they endeavoured to avoid; but the current of air was uniform from the height of 600 to 4200 feet. The barometer on the coast of the sea was 29,61 inches, and sunk to 23,94 inches. They found that by working with their oars, they accelerated their course. In the prosecution of their voyage, which was 150 miles, they heard two claps of thunder; and the cold occasioned by the approach of stormy clouds made the thermometer fall from 77° to 59°, and condensed the inflammable air in the balloon, so as to make it descend very low. From some experiments they concluded, that they were able by the use of two oars to deviate from the direction of the wind about 22°. But this experiment requires repetition, in order to ascertain with accuracy the effect here ascribed to oars.

The second aerial voyage in England was performed by Mr. Blanchard and M. Sheldon, professor of anatomy to the Royal Academy, the first Englishman who ascended with an aerostatic machine. This experiment was performed at Chelsea on the 16th of October. The wings used on this occasion seemed to have produced no deviation in the machine's tracks from the direction of the wind. Mr. Blanchard, having lauded his friend about the distance of 14 miles from Chelsea, proceeded alone with different currents; and ascended so high as to experience great difficulty of breathing: a pigeon also, which flew away from the boat, laboured for some time with its wings, in order to sustain itself in the rarefied air, and after wandering for a good while returned and rested on one side of the boat. Mr. Blanchard perceiving the sea before him descended near Runsey, about 75 miles from London, having travelled at the rate of nearly 20 miles an hour.

On the 12th of October, Mr. Sadler, of Oxford, made a voyage of 14 miles from that place in 17 minutes, with an inflammable air balloon of his own contrivance and construction.

Mr. Blanchard's fifth aerial voyage was performed from London on the 30th of November, in company with Dr. J. Jefferies, a native of America. This voyage was about twenty-one miles. It does not appear that they derived any advantage from their oars in directing the course of the balloon.

On the 4th of January 1785, Mr. Harper ascended with an inflammable air-balloon from Birmingham: he went to the distance of 50 miles in about an hour and a quarter, and found no inconveniences beside such as might be expected from the changes of wet and cold, and a temporary deafness. The thermometer descended from 40° to 28°.

On the 7th of January Mr. Blanchard, accompanied by Dr. Jefferies, departed with the balloon, which had carried him five times through the air, from Dover castle towards the French coast. In their passage they were under a necessity of throwing away every thing which they had with them in the boat, and to part even with their clothes, in order to prevent the balloon from falling into the sea: but

as they approached the land, it began to rise: and in two hours they reached the high grounds near Calais, and the balloon rising still higher over the land, they descended safely in the forest of Guinnes. In consequence of this voyage the king of France presented Mr. Blanchard with a gift of 12000 livres, and granted him a pension of 1200 livres a year. A bottle which was thrown out of the boat in the time of their danger, struck the water with such force, that the shock was heard at a considerable elevation, and sensibly felt on the car and balloon.

On the 19th of January Mr. Crosbie ascended at Dublin with an inflammable air balloon to a great height, and rose so rapidly as to be out of sight in $3\frac{1}{2}$ minutes. By opening the valve he descended suddenly as he approached very near the sea. On the 23d of March Count Zambecari and Admiral Sir Edward Vernon ascended at London, and sailed to Horsham in Sussex, at the distance of 35 miles, in less than an hour. At the height of about two miles, the barometer having fallen from 30.4 inches to 20.8 inches, an accident endangered them, and obliged them to descend. In their descent they passed through a dense cloud, which covered them with snow. They observed that the balloon revolved perpetually round its vertical axis, with such rapidity as to perform each revolution in four or five seconds; they also mention a kind of rustling noise, which they heard among the clouds, and that the balloon was greatly agitated in its descent. On the 5th of May, Mr. Sadler and Mr. Windham ascended at Moulsey Hurst; and were driven by a current of air towards the sea. They fortunately descended at the conflux of the Thames and Medway; but the cords of their machine being released, it instantly ascended and floated to a considerable distance, and was taken up by a trading vessel at sea, where it fell. On the 12th of May, Mr. Crosbie ascended at Dublin, but soon came down again with a velocity which alarmed the spectators. Upon his descent, Mr. McGuire, a college youth, sprung into the machine, and was carried off by the ascending balloon towards the Channel; he at length fell into the sea, and was taken up by a boat dispatched for his relief, just when his strength was exhausted with swimming, and thus his life was saved.

The fate of M. P. de Rozier, the first aerial navigator, and of his companion M. Romain, has been much lamented. They ascended at Boulogne on the 15th of June, with an intention of crossing the Channel to England. Their machine consisted of a spherical balloon 37 feet in diameter, filled with inflammable air; and under this balloon was suspended a small Montgolfier, or fire-balloon, ten feet in diameter. This Montgolfier was designed for rarefying the atmospheric air, and thus diminishing the specific gravity of the whole apparatus. For the first twenty minutes they seemed to pursue the proper course; but the balloon seemed to be much inflated, and the aeronauts appeared anxious to descend. Soon however, when they were at the height of about three quarters of a mile, the whole apparatus was in flames, and the unfortunate adventurers fell to the ground, and were killed on the spot.

On the 19th of July Mr. Crosbie ascended at Dublin, with a view of crossing the Channel to England. To a wicker basket of a circular form, which he had substituted for the boat, he had affixed a number of bladders, for the purpose of rendering his gallery buoyant, in case of a disaster at sea. The height to which he ascended at one time was such, that by the intense cold his ink was frozen, and the mercury sunk into the ball of the thermometer. He himself was sick, and he felt a strong impression on the tympanum of his ears. At his utmost elevation he thought

himself stationary; but on discharging some gas, he descended to a very rough current of air blowing to the north. He then entered a dense cloud, and experienced strong blasts of winds, with thunder and lightning, which brought him with rapidity towards the surface of the water. The water soon entered his car; the force of the wind plunged him into the ocean; and it was with difficulty that he put on his cork jacket. The bladders which he had prepared were now found of great use. The water, added to his own weight, served as ballast; and the balloon maintaining its poise, answered the purpose of a sail, by means of which, and a snatch-block to his car, he moved before the wind as regularly as a sailing vessel. He was at length overtaken by some vessels that were crowding sail after him, and conveyed to Dunleary, with the balloon towed after them. On the 22d of July, Major Money, who ascended at Norwich, was driven out to sea, and after having been blown about for about two hours, he dropped into the water. After much exertion for preserving his life, and when he was almost despairing of relief, he was taken up by a revenue cutter in a state of extreme weakness; having been struggling to keep himself above water for about seven hours. The longest voyage that had been hitherto made was performed by Mr. Blanchard towards the end of August. He ascended at Lille, accompanied by the chevalier de L'Epinaud, and traversed a distance of 300 miles before they descended. On this, as well as on other occasions, Mr. Blanchard made trial of a parachute, in the form of a large umbrella, which he contrived for breaking the fall in case of any accident. With this machine he let down a dog, which came to the ground gently, and unhurt.

On the 8th of September Mr. Baldwin ascended from the city of Chester, and performed an aerial voyage of 25 miles in two hours and a quarter. His greatest elevation was about a mile and an half, and he supposes that the velocity of his motion was sometimes at the rate of 30 miles an hour. He has published a circumstantial account of his voyage, described the appearances of the clouds as he passed through them, and annexed a variety of observations relating to aerostation, which render his treatise valuable and interesting to those who wish to acquaint themselves with this subject. It would be tedious to recount the aerial expeditions that were performed in various parts of our own country, as well as on the continent, in the whole course of the year 1785; more especially as they have afforded us no experiment or discovery of any peculiar importance. The most persevering aerial navigator has been Mr. Blanchard. In August 1788, he ascended at Brunswick for the thirty-second time. Within two years from the first discovery of this art of navigating the atmosphere, more than forty different persons performed the experiment without any material injury; and it may be justly questioned, says Mr. Cavallo, whether the first forty persons, who trusted themselves to the sea in boats, escaped so safely. The catastrophe that befel Rozier, and the unpleasant circumstances that have happened to some of the aeronauts in our own country, have been owing not so much to the principle of the art, as to want of judgment, or imprudent management in the conduct of it.

We shall close this abstract of the history of aerostation with the observations of a very competent judge on the respective advantages and disadvantages of balloons made with inflammable air, and of those that are raised by means of hot air, to the former of which he gives the preference. The principal comparative advantages of the rarefied air-balloons are, their being filled with little or no expence; their not requiring to be made of so expensive materials; and the com-

buftibles necessary to fill them being found almost every where, so that when the provision of fuel is exhausted, the aeronaut may descend and recruit his fuel, in order to proceed on his voyage. But they must be larger than balloons of the other sort, in order to take up the same weight; and the presence of fire is a continual trouble and a continual danger. Experience has, in many instances, evinced the disastrous consequences that have attended them. On the other hand, the inflammable air balloon must be made of a substance impermeable to the subtle gas; the gas itself cannot be produced without a considerable expence; and it is not easy to find the materials and apparatus necessary for the production of it in every place. Improvements, however, daily occur in the preparation of the coverings of these balloons, so as to render them nearly impermeable to the inflammable air: and it has been found that an inflammable air-balloon, 30 feet in diameter, may be so made as to sustain two persons and a considerable quantity of ballast in the air for more than 24 hours, when properly managed; and one man might possibly be supported by the same machine for three days.

AEROSTATION, practice of. The shape of the balloon is one of the first objects of consideration in the construction of this machine. As a sphere admits the greatest capacity under the least surface, the spherical figure, or that which approaches nearest to it, has been generally preferred. However, since bodies of this form oppose a greater surface to the air, and consequently a greater obstruction to the action of the oar or wings than those of some other form, and therefore cannot be so well guided in a calm, or in a course different from the direction of the wind, it has been proposed to construct balloons of a conical or oblong figure, and to make them proceed with their narrow end forward. Mr. Hooke, an ingenious writer, who is now publishing a translation of the works of Leeuwenhoek, in his *Thoughts on the farther Improvement of Aerostation*, suggests the shape of a fish as the most proper: the sharp head, under such a form, will serve to divide the resisting fluid, and open a passage, and the tail will serve as a rudder to steer its course. He also proposes to fix a seat for the traveller in the lower part of the body of the fish, or in the centre of gravity of the whole mass, so that the machine may be always horizontal, and that the impulse of any force used there may actuate the whole body. And he farther suggests, that the traveller should be furnished with instruments of sufficient surface to take hold of the air, and of sufficient strength to bear the whole exertion of his muscular force, analogous in their form and situation to the fins of fishes. But by adopting the oblong shape, the surface, and consequently the weight of the cover, must be augmented, in order to obtain the same lifting power with that of a sphere, both because its capacity will be less under the same surface, and because its capacity must be made greater in order to compensate for the augmentation of weight. Besides, an oblong machine cannot easily be kept with the smallest part forward in the atmosphere: and if it should turn sideways, as it probably might, the proposed advantage would thereby be lost: not to add, that accidental circumstances might occur which would endanger its overturning.

In order to expedite the calculations that relate to the construction of a balloon of a spherical form, it should be remembered, that the circumferences of spheres are as their diameters; their surfaces as the squares; and their solid contents as the cubes of the diameters. The proportion of the diameter to the circumference of a circle, *i. e.* 7 to 22, or 1 to 3 $\frac{1}{7}$, should be recollected; so

that if the diameter of a balloon be 35 feet, its circumference will be 110 feet. If the diameter be multiplied by the circumference, the product will be the surface of the sphere; *i. e.* $35 \times 110 = 3850$ square feet. If this surface be divided by the breadth (in feet) of the stuff of which the balloon is made, the quotient will be the number of feet in length necessary for constructing the balloon: thus if the stuff be

3 feet wide, $\frac{3850}{3} = 1283\frac{1}{3}$ feet, or 428 yards nearly, which is the quantity for a balloon of 35 feet in diameter. By knowing the weight of a given piece of the stuff, as of a square yard or square foot, it is easy to find the weight of the whole bag, by multiplying the surface in square feet or yards by the weight of a square foot or yard; *e. g.* if each square yard weigh 16 ounces, or one pound, the whole bag will weigh 428 pounds. Again, the capacity, or solid content of the sphere, may be found by multiplying $\frac{1}{6}$ of the surface by the diameter, or by taking $\frac{1}{4}$ of the cube of the diameter; thus, in the present instance, we shall have 22458 cubic feet for the capacity of the balloon, or the number of cubic feet of air which it will displace. From the content and surface of the balloon, we may deduce its power of ascension or levity in the following manner:—a cubic foot of air weighs, at an average, about 1 $\frac{1}{2}$ ounce, and adding to the number 22458, its fifth part, we shall have 26950 ounces, or 1684 pounds, for the weight of the common air displaced by the balloon. From this weight, deducting the weight of the bag, or 428 pounds, there will remain 1256 pounds expressing the levity of the balloon, independently of the contained air. If this be inflammable air, its weight varies from $\frac{1}{4}$ to $\frac{1}{7}$ the weight of common air; if it be taken at $\frac{1}{6}$ of the weight of common air, then $\frac{1684}{6} = 280$ pounds will denote the weight of the air filling the balloon; and taking this from 1256, *i. e.* $1256 - 280$, will leave 976 pounds, the power of ascension of the balloon, or the weight which it will carry up, consisting of the car, ropes, passengers, ballast, and other necessities. If heated air be used, the density of this is diminished about one-third; and therefore, taking from 1684 one-third of itself, there will remain 1123 for the weight of the contained warm air, and this subtracted from 1256, leaves 133 pounds for the levity of the balloon; but as this is not sufficient for carrying up the car, passengers, &c. it is evident that a larger balloon, on Montgolfier's principle, is necessary for the same purpose that may be effected by a smaller one of inflammable air. To estimate the power of ascension corresponding to any given weight, *e. g.* 1000 pounds; since the levities are nearly as the cubes of the diameters, and consequently the diameters as the cube roots of the levities; and the levities being as 133 to 1000, *i. e.* nearly as 1 to 8, the cube-roots are as 1 to 2; consequently 1 : 2 :: 35 : 70 feet, the diameter of a Montgolfier, made of the same thickness of stuff as the former, and capable of lifting 1000 pounds. Pursuing the same kind of calculation, it is easy to estimate the size of a balloon, made of stuff of a given thickness, and filled with air of a given density, that will just float in air. From the weight of a cubic foot of common air, subtract that of a cubic foot of the lighter or contained air; then divide 6 times the weight of a square foot of the stuff by the remainder, and the quotient will be the diameter, in feet, of the balloon that will just float at the surface of the earth. Suppose the stuff to be 1 pound to the square yard, or $\frac{16}{9}$ ounces to the square foot, and this multiplied by 6 gives $1\frac{2}{3}$; then the cubic foot of common air weighing $1\frac{1}{2}$ ounce, and of heated air $\frac{1}{3}$ of the same, the difference being $\frac{2}{3}$;

consequently¹² divided by $\frac{2}{3}$, gives $26\frac{2}{3}$ feet, which is the diameter of a Montgolfier that will just float: but if inflammable air, \therefore the weight of common air, be used, the difference between $1\frac{1}{2}$ and $\frac{1}{6}$ of it is one; by which dividing $\frac{32}{3}$ or $10\frac{2}{3}$, the quotient $10\frac{2}{3}$ feet will be the diameter of an inflammable air-balloon that will just float. If the diameter, in either of these cases be increased, the respective balloons will ascend in the atmosphere.

In order to determine the height to which a given balloon will rise, when the diameter of the balloon, and the weight that exactly balances it are given, proceed in the following manner:—compute the contents of the globe in cubic feet, and divide its restraining weight in ounces by this content, and the quotient will be the difference in density or specific gravity of the atmosphere at the surface of the earth, and that at the height to which the balloon will rise; subtract this difference or quotient from $1\frac{1}{2}$ or 1, 2, the density at the earth, and the remainder will be the density at that height; then the height corresponding to that density will be found with sufficient exactness in the annexed Table.

e. g. Let the diameter of the balloon be 35 feet, its capacity 22458, and the levity of the first 976 pounds, or 15616 ounces; the quotient of the latter number divided by the former, *i. e.* $\frac{15616}{22458}$ is .695, which is the

density at the utmost height, and to which in the Table corresponds somewhat less than $2\frac{1}{2}$ miles, and this is the height to which the balloon will ascend. When the same balloon was filled with heated air, its levity was equal to 133 pounds, or 2128 ounces, which divided by 22458, the capacity, gives the quotient, .095; and this subtracted from 1.200, leaves 1.105 for the density; to which, in the Table corresponds half a mile, or more nearly $\frac{1}{3}$ of a mile. Such are the heights to which these balloons would nearly ascend, if they retained their figure, and lost none of the contained air: or, more precisely, these are the heights at which they would settle; for their acquired velocity would at first carry them above these heights, till their motion would be destroyed; and then they would descend below these heights, though not so much as they had gone above them: after which they would reascend, and pass these heights again, but not so far as they had gone below them; thus vibrating alternately above and below these heights, but every time less and less. These calculations for finding the height to which the balloon will ascend, are formed independently of the different states of the thermometer at the highest point and at the surface of the earth; but the allowances to be made on this account will appear from what is delivered under the article ATMOSPHERE.

Next to the shape, it is necessary to consider the stuff that is most proper for forming the envelope of the inflammable or rarefied air. Silk stuff, especially that which is called lutestring, properly varnished, has been most commonly used for inflammable air-balloons: and common linen, lined within and without with paper, varnished, for those of rarefied air. Varnished paper, or gold beater's skin, will answer the purpose for making small inflammable air-bal-

Height in miles.	Density.
0	1.200
$\frac{1}{4}$	1.141
$\frac{1}{2}$	1.085
$\frac{3}{4}$	1.031
1	0.980
$1\frac{1}{4}$	0.932
$1\frac{1}{2}$	0.886
$1\frac{3}{4}$	0.842
2	0.800
$2\frac{1}{4}$	0.761
$2\frac{1}{2}$	0.723
$2\frac{3}{4}$	0.687
3	0.653

loons; and the small rarefied air-balloons may be made of paper without any varnish or other preparation.

The stuff for large balloons of both kinds require some previous preparation. The best mode of preparing the cloth for a machine upon Montgolfier's principle, is first to soak it in a solution of sal ammoniac and size, using one pound of each to every gallon of water; and when the cloth is quite dry, to paint it over with some earthy colour, and strong size or glue. It may be also varnished over, when perfectly dry, with some stiff oily varnish or simple drying linseed oil; which would dry before it penetrates quite through the cloth.

The varnish for the silk or linen of the inflammable air-balloons should be impermeable to the inflammable gas, pliable, and sufficiently dry to adhere firmly to the stuff. In France much has been said of the elastic gum varnish; but the composition of it is kept a secret. This gum is known to be soluble in divers essential oils, and also by vitriolic ether. The former solution forms a varnish which never perfectly dries: the latter dries readily, but the solution is too dear for common use. The following varnish has been recommended. To one pint of linseed oil, add two ounces of litharge, two ounces of white vitriol, and two ounces of gum sandarach; boil the whole for about an hour over a slow fire; then let it cool: separate it from the sediment, or strain it through a sieve, and dilute it with a sufficient quantity of spirits of turpentine. But the best varnish for an inflammable air-balloon is made with bird-lime. Mr. Cavallo directs to prepare it in the following manner, which, in his opinion, is preferable to that of M. Faujas de Saint Fond. In order to render linseed oil drying, boil it with two ounces of saccharum saturni and three ounces of litharge, for every pint of oil, till the oil hath dissolved them; then put a pound of bird-lime and half a pint of the drying oil into a pot of iron or copper, holding about a gallon; and let it boil gently over a slow charcoal fire till the bird-lime ceases to crackle; then pour upon it two pints and a half of drying oil, and boil it for about an hour longer, stirring it often with an iron or wooden spatula. As the varnish in boiling swells much, the pot should be removed from the fire and replaced when the varnish subsides. Whilst it is boiling, it should be occasionally examined, in order to determine whether it has boiled enough. For this purpose, take some of it upon the blade of a large knife, and after rubbing the blade of another knife upon it, separate the knives, and when on their separation the varnish begins to form threads between the two knives, it has boiled enough, and should be removed from the fire. When it is almost cold, add about an equal quantity of spirits of turpentine, mix both well together, and let the mass rest till the next day; then having warmed it a little, strain and bottle it. If it is too thick, add more spirits of turpentine. This varnish should be laid upon the stuff, when perfectly dry, in a luke-warm state; a thin coat of it upon one side, and about twelve hours after two other coats should be laid on, one on each side, and in twenty-four hours the silk may be used.

Mr. Blanchard's method of making elastic gum varnish for the silk of a balloon is as follows. Dissolve elastic gum, cut small, in five times its weight of spirits of turpentine, by keeping them some days together; then boil one ounce of this solution in eight ounces of drying linseed oil for a few minutes, and strain it. Use it warm.

The pieces of which an inflammable air-balloon is to be formed, must be cut of a proper size, according to the proposed dimensions of it, when the varnish is sufficiently dry. The pieces that compose the surface of the balloon are like

those gores that form the superficies of a globe: and the best method of cutting them is to describe a pattern of wood or stiff card-paper, and to cut the silk or stuff upon it. One of these pieces, that may serve as a pattern for others, is represented in *Plate I. Pneumatics, fig. 2.* In this figure, suppose *AE* and *BC* to be two right lines perpendicular to each other. Then find the circumference answering to the given diameter of the balloon in feet and decimals of a foot; and make *AD* and *DE* each equal to a quarter of the circumference, so that *AE* may be equal to half the circumference. Divide *AD* into 18 equal parts, and to the points of division apply the lines *fg, bi, kl, &c.* parallel to each other, and perpendicular to *AD*. Divide the whole circumference into twice the given number of pieces, and make *DC* and *DB* each equal to the quotient of this division; so that *BC* will be equal to the greatest breadth of one of those pieces. Multiply this quotient or *DC* by the decimals annexed to *fg*, viz. 0.99619, and the product expresses the length of *fg*; and multiply *DC* by the decimals annexed to *bi*, and the product expresses the length of *bi, &c.* Having thus found the lengths of all these lines, draw by hand a curve line, passing through their extremities, and this will be the edge of one quarter of the pattern. The other quarters *ABD, EBD, EDC*, may be easily described by applying to each of them a piece of paper equal to *ADC*. Suppose the diameter of the balloon to be 20 feet, and that it is to be made of 12 pieces. In order to draw the pattern, find the circumference of the balloon, which is 62.83 feet, and dividing it by 4, the quotient is 15.7 feet: consequently *AD* and *DE* will be each equal to 15.7 feet. Divide the circumference 62.83 by 24, or double the number of pieces that are to form the balloon; and the quotient 2.618 feet will be the length of *DC* or *BD*; therefore *BC* is equal to 5.236 feet. Then dividing *AD* into 18 equal parts, and drawing the parallel lines from the points of division, find the length of these lines by multiplying 2.618 by the decimals annexed to that line: thus, 2.618 multiplied by 0.99619 gives 2.608 feet for the length of *fg*; and multiplying 2.618 by 0.98481, we shall have 2.578 feet for the length of *bi, &c.* The pieces cut after such a pattern should be left about one half or three quarters of an inch all round larger than the pattern, in order to allow for the seams. They may be joined by laying about half an inch of the edge of one piece over the edge of the other, and sewing them with a double stitching. Mr. Blancard joins them very expeditiously in the following manner. He lays about half an inch of the edge of one piece flat over the edge of the other, and passes a hot iron over it; in doing which, a piece of paper ought to be laid both under and over the silk. The joining may be rendered more secure, by running it with a silk thread, and sticking a ribband over it. The ribbands laid over seams may be stuck with common glue, provided the varnish of the silk is properly dried. When the glue is quite dry, the ribbands should be varnished over, to prevent their being unglued by the rain.

To the upper part of the balloon there must be adapted a valve, opening inward, to which is annexed a string passing through a hole made in a small round piece of wood which is fastened to the lowest part of the balloon opposite to the valve, to the boat below it; so that the aeronaut may open it as occasion requires, and let the inflammable air out of the balloon. To the lower part of the balloon are fixed two pipes of the same stuff with the covering, six inches in diameter for a balloon of thirty feet, and much larger for balloons of greater size, and long enough to reach the boat. These pipes are the apertures through which the inflammable air is introduced into the balloon.

The boat may be made of wicker-work, and covered with leather, well painted or varnished over. The best method of suspending it is by means of ropes, proceeding from the net which goes over the balloon. This net should be formed to the shape of the balloon, and fall down to the middle of it, and have various cords proceeding from it to the circumference of a circle, about two feet below the balloon; and from that circle other ropes should go to the edge of the boat. This circle may be made of wood, or of several pieces of slender cane bound together. The meshes of the net may be small at top, against which part of the balloon the inflammable air exerts the greatest force, and increase in size as they recede from the top. A hoop has been sometimes put round the middle of the balloon for fastening the net. This is not absolutely necessary; but when used, it is best made of pieces of cane bound together, and covered with leather. When the balloon and its appendages are constructed, the next object of importance is to procure proper materials for filling it. With respect to those inflated by heated air, nothing need be said till the method of filling them is described.

Inflammable air for balloons of the other kind may be obtained in several ways; but the best methods are by applying acids to certain metals; by exposing animal, vegetable, and some mineral substances, in a close vessel, to a strong fire; or by transmitting the vapour of certain fluids through red-hot tubes.

In the first of these methods, iron, zinc, and vitriolic acid, are the materials most commonly used. The vitriolic acid must be diluted with five or six parts of water. Iron may be expected to yield in the common way about 1700 times its own bulk of gas; or $4\frac{1}{2}$ ounces of iron, the like weight of oil of vitriol, and $22\frac{1}{2}$ ounces of water will produce one cubic foot of inflammable air: six ounces of zinc, an equal weight of oil of vitriol, and 30 ounces of water, are necessary for producing the same quantity. It is more proper to use the turnings or chippings of great pieces of iron, as of cannon, &c. than the filings of that metal; because the heat attending the effervescence will be diminished, and the diluted acid will pass more readily through the interstices of the turnings, when they are heaped together, than through the filings which stick closer to one another. The weight of the inflammable air, thus obtained by means of acid of vitriol, is, in the common way of procuring it, generally one-seventh part of the weight of common air; and with the necessary precautions for philosophical experiments, less than one-tenth of the weight of common air. The other elastic fluids, which are generated with the inflammable air, may be separated from it by passing the inflammable air through water, in which quick-lime has been dissolved; the water will absorb these fluids, cool the inflammable air, and prevent its overheating the balloon, when it is introduced into it. As white vitriol is sold much dearer than the vitriol of iron, it will be a saving to make the inflammable air by means of zinc and vitriolic acid, rather than of this acid and iron: because the sale of the white vitriol arising from the former will, in a degree, be a compensation for the expence of the materials.

Inflammable air may also be obtained at a much cheaper rate by the action of fire on various substances; but the gas thus obtained is not so light as that produced by the effervescence of acids and metals. The substances proper to be used for this purpose are pit-coal, asphaltum, amber, rock oil, and other minerals; wood, and especially oak, camphor oil, spirits of wine, ether, and animal substances, which yield air of different degrees and of various specific gravity. But pit-coal is the substance most proper to be used. A pound

of pit-coal, exposed to a red heat, yields about three cubic feet of inflammable air, which, whether it be passed through water or not, weighs about one-fourth of the weight of an equal bulk of common air.

Dr. Priestley observes, that animal or vegetable substances will yield six and even ten times more inflammable air, when the fire is suddenly increased than when it is gently raised, though it be afterwards made very strong. And Mr. Cavallo informs us, that the various substances above enumerated generally yield all their inflammable air in about an hour's time. The usual method is to inclose the substances in earthen or iron vessels, and thus to expose them to a strong fire sufficient to make the vessels red-hot; the inflammable air proceeding from the aperture of the vessel, is received into a tube or refrigerator, and passing through the tube or worm, is at last collected in a balloon or other vessel. A gun-barrel has been often used for essays of this kind. The manner of conducting this process is particularly described by Mr. Cavallo, *ubi infra*.

The last method of obtaining inflammable air was lately discovered by Mr. Lavoisier, and also by Dr. Priestley. Mr. Lavoisier made the steam of boiling water pass through the barrel of a gun, kept red-hot by burning coals. Dr. Priestley uses, instead of the gun-barrel, a tube of red-hot brass, upon which the steam of water has no effect, and which he fills with the pieces of iron which are separated in the boring of cannon. By this method he obtains an inflammable air, the specific gravity of which is to that of common air as 1 to 13. In this method, a tube about three quarters of an inch in diameter, and about three feet long, is filled with iron turnings; then the neck of a retort or close boiler is luted to one of its ends, and the worm of a refrigerator is adapted to its other extremity. The middle part of the tube is then surrounded with burning coals, so as to keep about one foot in length of it red-hot, and a fire is always made under the retort or boiler sufficient to make the water boil with vehemence. In this process a considerable quantity of inflammable air comes out of the worm of the refrigerator. It is said that iron yields one half more air by this means, than by the action of vitriolic acid. See HYDROGEN.

Balloons of the smaller size, such as those of two or three feet in diameter, and also bladders, may be filled with inflammable air, after passing it through water, by means of the following simple apparatus. See *Plate I. Pneumatics, fig. 3*. A is the bottle that contains the ingredients which produce the gas: BCD is a tube in form of a syphon, fastened by one extremity into the neck of this bottle, and passing through a hole of the stopper of another bottle E, it extends so far as almost to touch the bottom of this bottle, which is nearly full of water. To another hole made in the cork of the bottle E is adapted another tube, to the outward extremity of which a bladder, or the aperture of the balloon is tied. The inflammable air, coming out of the aperture D of the tube, passes through the water of the bottle E, and then enters into the bladder or balloon. Two small casks might be used instead of the bottles A and E.

Another apparatus for producing hydrogen and conveying it into a balloon is exhibited in *fig. 4*. ABC is a vessel made of clay, or of iron, in the form of a Florence flask; and the substance yielding gas is introduced into it so as to occupy about $\frac{1}{4}$ th, or less, of its cavity. If the substance swell much by the action of the fire applied to it, a tube of brass, or first a brass and then a leaden tube must be luted to the neck C of the vessel, and the extremity D of the tube is made to pass through the water of a tub H I, and to terminate under an inverted vessel E F, to the upper aperture

of which the balloon, or a tube going to the balloon is adapted. When the part, A B, of the vessel is put into the fire, and made red-hot, the inflammable air that is generated will come out of the tube C D, and passing through the water of the tub, it will at last enter into the balloon G. As a considerable quantity of common air remains in the inverted vessel E F, before the operation is begun, it should have a stop-cock, K, through which it may be drawn out by suction, and then the water will ascend as high as the stop-cock. The aperture of the vessel, E F, should be at least one foot below the surface of the water in H I; and the fire should be at a sufficient distance from the tub H I, that the inflammable air, if any of it should escape, may not take fire and do injury.

The method of filling large aerostatic machines with rarefied air is as follows. A scaffold ABCD (*Plate II. fig. 5*.) the breadth of which is at least two-thirds of the diameter of the machine, is elevated about six or eight feet above the ground. From the middle of it descends a well E F, rising about two or three feet above it, and reaching to the ground, furnished with a door or two, through which the fire in the well is supplied with fuel. The well should be constructed of brick or of plastered wood; and its diameter should be somewhat less than that of the machine. On each side of the scaffold are erected two masts H I, K L, each of which has a pulley at the top, and rendered firm by means of ropes K G, K P, H P, H G. The machine to be filled is placed on the scaffold, with its neck round the aperture of the well. The rope passing over the pulleys of the two masts, serves, by pulling its two ends, to lift the balloon about fifteen feet or more above the scaffold: and the rest of the machine is represented by the dotted lines in the figure M N O. The machine is kept steady and held down, whilst filling, by ropes passing through loops or holes about its equator; and these ropes may be easily disengaged from the machine, by slipping them through the loop, when it is able to sustain itself. The proper combustibles to be lighted in the well are those which burn quick and clear, rather than such as produce much smoke; because it is hot air, and not smoke, that is required to be introduced into the machine. Small wood and straw have been found to be very fit for this purpose. Mr. Cavallo observes, as the result of many experiments with small machines, that spirits of wine are upon the whole the best combustible; but its price may prevent its being used for large machines. As the current of hot air ascends, the machine will soon dilate, and lift itself above the scaffold and gallery, which was covered by it. The passengers, fuel, instruments, &c. are then placed in the gallery. When the machine makes efforts to ascend, its aperture must be brought, by means of the ropes annexed to it, towards the side of the well, a little above the scaffold. The fire-place is then suspended in it; the fire lighted in the grate; and the lateral ropes being slipped off, the machine is abandoned to the air. It will appear in the atmosphere as it is represented in *fig. 6*. It has been determined by accurate experiments, that only one-third of the common air can be expelled from these large machines; and therefore, the ascending power of the rarefied air in them can be estimated as only equal to half an ounce avoirdupois for every cubic foot. The apparatus for filling an inflammable air balloon is represented in *fig. 7*. A, A are two tubs, about three feet in diameter, and nearly two feet deep, inverted in larger tubs, B, B, full of water. At the bottom of each of the inverted tubs there is a hole, to which is adapted a tin tube E, about seven inches in diameter, and seven or eight inches long. To these tubes the silken tubes of the

balloon are tied. Each of the tubs, B, is surrounded by several strong casks, so regulated in number and capacity, as to be less than half full, when the materials are equally distributed. In the top of each of these casks are two holes; and to one of the holes is adapted a tin tube, formed so as to pass over the edge of the tub B, and through the water, and to terminate with its aperture under the inverted tub A. The other hole, which serves for supplying the cask with materials, is stopped with a wooden plug. These tin tubes may be about three inches and a half in diameter, and the other holes may be smaller. Two masts, with a rope, &c. are used for this machine, as well as for the former, although they are not absolutely necessary; because the balloon, by means of a narrow scaffold, or other contrivance, may be elevated five or six feet above the level of the tubs A A. When the balloon is to be filled, the net is put over it and suspended, as exhibited in C D F: and having expelled all the common air from it, its silk tubes are fastened round the tin tubes E E, and the materials in the casks are properly proportioned; the iron being first put in, then the water, and lastly the vitriolic acid. The balloon will soon be inflated by this inflammable air, and support itself without the aid of the rope G H. As the filling advances, the net is adjusted round it, the cords, proceeding from the net, are fastened to the hoop M N; the boat I K is suspended from the hoop M N, and every thing necessary for the voyage is deposited in the boat. When the balloon is a little more than three quarters full, the silken tubes are separated from the tin tubes, and their extremities being tied, they are placed in the boat. Finally, when the aeronauts are seated in the boat, the lateral ropes are slipped off, and the machine ascends in the air, appearing as in fig. 8. In order to produce such a bulk of inflammable air as is necessary for a balloon of 30 feet in diameter, whose capacity is 141,37 cubic feet, there will be required about 3900 pounds of iron turnings, 3900 pounds of vitriolic acid, and 19500 pounds of water. The balloon will not be above three quarters full.

These proportions, stated by Mr. Cavallo, are too great with respect to the metal and acid, and too small with regard to the water. Mr. Lunardi, who had considerable experience in the practice of aërostation, filled his balloons at Edinburgh and Glasgow, with about 2000 pounds of the chippings of cannon procured from Carron, the same quantity of vitriolic acid, and 12,000 pounds of water. The iron was placed in layers in his vessels, with straw between them, in order to enlarge the surface exposed to the action of the acid. He used only two large casks, which were sunk in the ground, and conveyed the gas into the balloon without passing through water; and he contrived to fill his balloon in less than half an hour, which operation had on former occasions required at least two hours.

The inflammable air with which they fill their balloons at the Aërostatic Institute, not long since established in France, is obtained by the following method, which is simple and not very expensive. Six cylinders, or tubes of iron, are fixed by masonry in a furnace of easy and expeditious construction, in such a manner that the two ends of each cylinder project out of the furnace; and these are furnished with strong covers or lids of iron. Into these cylinders are introduced tubes of metal, one of which serves to convey warm water into the red-hot cylinder, and the other to convey the air which is produced through a reservoir filled with caustic ley, into the balloon. The cylinders are partly filled with the chippings or turnings of iron that are procured from the boring of cannon. The excessive heat of the furnace, which is maintained by a supply of char-

coal during the operation, is communicated to the cylinders and their contents. In this state, boiling water is conveyed by one of the tubes to each cylinder; and as soon as it communicates with the inflamed iron, the water is decomposed: the one part, called the oxygen, attaches itself to the iron and calcines it; but the other part, or the hydrogen, is combined with a quantity of the igneous substance, called caloric, and becomes hydrogenous gas, or inflammable air, which remains in a permanent state of elastic fluidity, and weighs seven or eight times less than the atmospheric air. As the water contains a small quantity of carbon or fixed air, which would add weight to the air of the balloon, it is made to pass through water in which caustic alkali has been dissolved. This fluid attaches the carbon to itself, and thus the pure inflammable air is conveyed into the balloon. The cylinders in this operation, are sometimes fused: for preventing which accident, a pyrometer is annexed to the extremity of the cylinder which projects from the furnace; and the fire is regulated by a scale connected with the pyrometer. The operation of filling a balloon, 30 feet diameter, in this way will occupy about four hours.

In estimating the ascending power of these machines, that of the inflammable air should be considered as equal to one ounce avoirdupois for every cubic foot, which is one sixth of the weight of common air; and therefore, if the capacity of a balloon is 12000 cubic feet, and three-fourths of it are filled with inflammable air, obtained from iron and diluted vitriolic acid, the ascending power of that gas may be estimated at 9000 ounces, or 562½ pounds; from which the weight of the covering, boat, and other appendages, must be subtracted.

The conduct of balloons, when constructed, filled, and actually ascending in the atmosphere, is an object of great importance in the practice of aërostation. The method generally used for elevating or lowering the balloons with rarefied air, has been the increase or diminution of the fire; and this is entirely at the command of the aeronaut, as long as he has any fuel in the gallery. The inflammable air-balloons have been generally raised or lowered by diminishing the weight in the boat, or by letting out some of the gas through the valve. But the alternate escape of the air in descending, and discharge of the ballast for ascending, will by degrees render the machine incapable of floating; for in the air it is impossible to supply the loss of ballast, and very difficult to supply that of inflammable air. These balloons will also rise or fall by means of the rarefaction or condensation of the inclosed air, occasioned by heat and cold. It has been proposed to aid a balloon in its alternate motion of ascent and descent, by annexing to it a vessel of common air, which might be condensed by lowering the machine, and rarefied again, by expelling part of it, for raising the machine. But a vessel adapted to this purpose must be very strong, and, after all, the assistance afforded by it would not be very considerable. M. Meunier, in order to attain this end, proposes to inclose one balloon filled with common air, in another filled with inflammable air: as the balloon ascends, the inflammable air is dilated, and of course compresses the internal balloon containing common air; and by diminishing its quantity, lessens its weight. If it should be necessary to supply this loss, he says it may be easily done by a pair of bellows fixed in the gallery. Others have proposed to annex a small machine with rarefied air to an inflammable air-balloon by ropes, at such a distance that the fire of the former might not affect the inflammable air of the latter: the whole apparatus, thus combined, of balloons formed on the two principles of heated and inflammable air,

might be raised or lowered by merely increasing or diminishing the fire in the lower balloon. Wings or oars seem to have contributed little to the effect of either raising or lowering balloons.

Many schemes have been proposed for directing the horizontal motion of balloons. Some have thought of annexing sails to a balloon, in order to give it the advantage of the wind; but to this proposal it has been objected, that as the aerostatic machines are at rest with respect to the air that surrounds them, they feel no wind, and consequently can derive no benefit from the sails. An ingenious writer observes, that the case of vessels at sea is quite different from that of balloons; because the former move with a velocity incomparably less than that of the wind impelling them, on account of the resistance of the water; and therefore, the difference between the velocity of the wind, and that of ships, occasions that stream of air which acts upon the sails. But a balloon, finding no resistance, acquires the same velocity with the surrounding air, and therefore can feel no wind. The same author adds, that the most rational projects for directing an aerostatic machine are those which propose to exert a force against the ambient air on one side of the machine, so as to move it in the opposite direction. Oars and wings are the only instruments that have been used for this purpose with any measure of success; but farther experiments are necessary to ascertain their effect. If wings or oars be used, the best method of moving them is by the immediate application of human power, as in the case of the oars of boats on the water. However they should be as large and light as possible; and they may be made of silk stretched between wires, tubes, or sticks. If they are flat they must be turned edgewise when they are moved in the direction of the balloon's course, and flat in the opposite direction. One of the wings, used by Mr. Blanchard, is represented in *fig. 9*. That used by Mr. Lunardi consisted of many silk shutters or valves *A B C D, D E C F*, &c. (*fig. 10*.) each of which opens only on one side, viz. *A D B C* upon the line *A B, D E C F* upon the line *D C*, &c; and by this construction, it becomes unnecessary to turn these oars edgewise. One of the wings, constructed by Zambeccari is exhibited in *fig. 11*, and is nothing more than a piece of silk stretched between two tin tubes set at an angle; and so contrived as to turn edgewise of themselves, when they go in one direction. *Fig. 12* represents one of the wings used by Messrs. Roberts, in the voyage of September 19th, 1784. The greatest effect produced by the wings of an aerostatic machine was that which occurred in this voyage. It is not difficult to determine what force is necessary to move a given machine in the air with any proposed velocity. Dr. Hutton found, from accurate experiments, that a globe of $6\frac{1}{8}$ inches in diameter, and moving with a velocity of 20 feet in a second, sustains a resistance from the air, which is equal to the weight or pressure of one ounce avoirdupois; and that with different surfaces and the same velocity, the resistances are directly proportional to the surfaces nearly; and also that, with different velocities, the resistances are proportional to the squares of the velocities nearly. By these data the resistance to move a given balloon with any velocity may be assigned. Let the balloon be 35 feet in diameter; then if it moved with the velocity of 20 feet per second, or almost 14 miles per hour, it would counteract a resistance equal to 271 pounds; with a motion of seven miles an hour, the resistance would be 68 pounds; and at three miles and an half in an hour, the resistance would be 17 pounds; and such is the force with which the aeronauts must act on the air in a contrary direction, in order to communicate such a degree

of motion to the machine. If the balloon move through a rarer part of the atmosphere than that at the surface of the earth, as $\frac{1}{4}$ d or $\frac{1}{4}$ th, &c. rarer, the resistance will be less in the same proportion; yet the force of the oars will be diminished as much; and therefore the same difficulty remains. It may be observed in general, that the aeronaut must strike the air, by means of his oars, with a force just equal to the resistance of the air or the balloon, and therefore he must strike that air with a velocity which must be greater as the surface of the oar is less than the resisted surface of the globe, but not in the same proportion, because the force is as the square of the velocity. Suppose that the aeronaut acts with an oar equal to 100 square feet of surface to move the balloon above-mentioned at the rate of 20 feet per second, or 14 miles an hour, then he must move this oar with the great velocity of 62 feet per second, or nearly 43 miles an hour: and so in proportion for other velocities of the balloon. Hence it is highly probable, that it will never be in the power of man to guide such machines with any tolerable degree of success, especially when any considerable wind blows, which is generally the case. A helm seems to have no particular power in directing the course of a balloon, for the same reason that has been alleged to evince the inefficacy of sails. We have not in air, as in water, says count de Mirabeau, in his Considerations on the Order of Cincinnati, the resource of a fixed point of action upon a fluid, which has also much greater resistance than air. He adds, that as there are different currents of air, sometimes in opposite directions, and balloons are capable of ascending and descending in search of these currents, this circumstance may favour the hope of directing aerostatic machines. Perhaps, an attention to the means by which birds fly against the wind, added to observations of comparative anatomy upon fishes and birds, which surmount the currents of the two fluids that are common to us and them, may also suggest new ideas with respect to the direction of balloons. Time alone, and numerous experiments, can bring these reflections to maturity, and realize the expectations suggested by them.

Several of the foreign journals have lately announced an invention of professor Danzel for directing an air-balloon through the atmosphere. With this view he has constructed two cylinders, or axles, to the ends of which are fixed, in the form of a cross, four sails, or oars, moveable at the point of their insertion in the cylinder, in such a manner, that when made to move round by means of a handle, the eight oars, like the cogs of a water-mill wheel, present successively to the air sometimes their flat side and sometimes their edge. To cause each oar to turn back on itself about the fourth part of a circle, M. Danzel has not only left sufficient play at the point where the stick of each oar is inserted in the cylinder, but has placed the stick in such a manner that the air itself makes the oar fall back, at each turn, with the necessary velocity and precision. Each of the two cylinders, armed with its four oars or sails, is destined to occupy one side of the balloon, with its four oars on each side. For a farther account of this apparatus and of its effect, see Philosophical Magazine, vol. iv. p. 108.

As parachutes, in the form of umbrellas, have been proposed in order to guard against accidents, and to break the fall in cases of sudden descent, we shall here annex a method of estimating the power of such defensive machines. A person, moving uniformly at the rate of ten feet per second, may descend with safety. For this uniform descent the resistance of the air must be equal to the whole descending weight. Suppose then that the weight of the aeronaut is 150 pounds, and that the parachute is flat and circular, and

made of such materials as that every square foot of it weighs two ounces, and that the weight increases in the proportion of the increase of the surface; in this case the diameter of the parachute, which will descend at the rate of ten feet per second, must be upwards of 78 feet; but if the parachute be concave on the lower side, its power will be rather greater, and its diameter may be less. In order to estimate the power of a flat circular parachute, or the resistance it meets with from air of a mean density, when descending with a given velocity, say as the number 800 is to the square of the velocity in feet, so is the square of the diameter in feet to a fourth number, which will be the resistance in pounds. And if it be required to know, with what velocity a parachute will descend with a given weight, say as the given diameter is to the square root of the weight, so is the number 284 to a fourth, which will be the velocity in air of a mean density. Thus, if the diameter of a balloon be 50, and its weight, together with that of a man, be 530 pounds, the square root of which is 23 very nearly; then $50 : 23 :: 284 : 13$; and therefore the man and parachute will descend with the velocity of 13 feet per second, which, as it is equal to that acquired by leaping freely from a height of two feet two inches, may be very safely sustained.

AEROSTATION, uses of. The advantages of an art, so lately discovered, have not yet been sufficiently ascertained; but we may reasonably expect, considering the progress it has made in so short a space of time, that many benefits may result from the farther prosecution of it. To say the least, it is unphilosophical to discourage future trials and improvements, because the uses of this art do not immediately appear. With regard to philosophical observations, derived from aerostation, it is acknowledged that very few have yet been made. The novelty of the discovery, and of the prospect, says Mr. Cavallo, has generally distracted the attention; and besides, most of the aerial voyages have been made by persons who had pecuniary profit alone in view, or who were stimulated to ascend in the atmosphere for the sake of the prospect, or by the vanity of adding their names to the list of aerial adventurers. Aerial navigation, considered as a mode of travelling between distant places, independently of its furnishing means of conveyance to places otherwise inaccessible, is attended with many advantages and conveniences. The aeronaut has much less trouble with this machine than a sailor with a ship in the most favourable circumstances. With a moderate wind, aerial navigators have often gone at the rate of forty or fifty miles an hour, and very commonly at the rate of thirty miles without any agitation, or even feeling the wind, and without the danger of losing time by being often becalmed. Aerostatic machines may serve the purpose of escaping from ships that cannot safely land, from besieged places, and from other circumstances of danger. A small balloon six or seven feet in diameter, says an anonymous author in his proposal of various means for saving the crews of vessels shipwrecked near the coast, would answer this purpose, by carrying to the shore a string capable of drawing a cord, with which several ropes might be afterwards conveyed to the vessel. They also expedite the communication of important events by signals, and serve for exploring, from a great elevation, adjacent coasts or regions, fleets and armies. To the latter of these purposes they have been actually applied by the French, in the course of the last war; and to the elevation of a balloon, and the information obtained in consequence of thus reconnoitering the army of the enemy, they ascribe the signal victory obtained in the battle of Fleurus in 1794. The balloon employed on this occasion,

was called the *Entrepreneur*, and it was under the direction of M. Coutel, the captain of the aeronauts at Meudon, accompanied by an adjutant and a general. He ascended twice in the same day, to the height of 220 fathoms, for the purpose of observing the position and manœuvres of the enemy. He continued each time four hours in the air, and corresponded with General Jourdan, who commanded the French army, by means of pre-concerted signals. The enterprise was discovered by the enemy, and a battery opened its fire against the ascending aeronauts; but they soon gained an elevation which was beyond the reach of their fire. This balloon was prepared under the direction of the *Aerostatic INSTITUTE*, for the use of the army of the north; as were also another called *Celeste*, for the army of the Sambre and Meuse, and the *Hercule* and *Intrepide*, for the army of the Rhine and Moselle. Another, thirty feet in circumference, and weighing 160 pounds, was destined for the army of Italy. A new machine, invented by M. Conte, the director of the Aerostatic Institute, was designed to aid the aeronauts in communicating intelligence, and was denominated the *Aerostatic TELEGRAPH*. Balloons may likewise serve to explore the state of the atmosphere at different heights, and to furnish observations, which shall illustrate a variety of phenomena, depending on the density, temperature, and other qualities of the air. From one experiment that has been already made we learn, that the air of a high region, preserved and examined by means of nitrous air, was found to be purer than the air below. The application of these machines to electrical experiments, is a very obvious use of which they are capable. The first person who employed them in this way seems to have been the Abbé Bertholon, at Montpellier. He raised several air balloons, furnished with long and slender wires, having their lower ends fastened to a glass stick, or other insulating substance; and thereby obtained from the wires electric fluid sufficient to shew the attraction, repulsion, and even the sparks of electricity. The existence of a continual electricity, of the positive kind, in a clear atmosphere, known indeed before, has been farther ascertained by strings fastened to balloons floating in the atmosphere. Some have apprehended danger from the electricity of the atmosphere; and have thought that a stroke of lightning, or the smallest electrical spark, happening near a balloon, might set fire to the inflammable air, and destroy both the machine and the adventurers. Mr. Cavallo has suggested several considerations for diminishing apprehensions of this kind. Balloons have been already raised in every season of the year, and even when thunder has been heard, without injury. In case of danger the aeronauts may either descend to the earth, or ascend above the region of the clouds and thunder storms. Besides, as balloons are formed of materials that are not conductors of electricity, they are not likely to receive strokes, especially as by being encompassed with air they stand insulated. Moreover, inflammable air by itself, or unmixed with a certain quantity of common air, will not burn; so that if an electric spark should happen to pass through the balloon, it would not set fire to the inflammable air, unless a hole was made in the covering.

For a variety of other important and useful particulars relating to the subject of aerostation, we must refer to Mr. Cavallo's curious and comprehensive work, entitled, the *History and Practice of Aerostation*, 8vo. 1785; which will afford the reader ample information concerning the principles of this art, and the history of its progress, the method of constructing and managing balloons, the nature and preparation of the materials of which they are formed, the observations and uses to which they are

adapted, and rules for estimating the heights to which they ascend.

See also for an account of several publications on this subject and abstracts of their contents, Monthly Review,

vol. lxix. p. 551.—vol. lxxi. p. 379.—vol. lxxiii. p. 99.—Meyer's *Fragments sur Paris*, tom. ii. p. 107, &c. Hutton's *Math. Dict.* Art. Aerostation.

Air

AIR, in *Physics*, a thin, fluid, elastic, transparent, ponderous, compressible, and dilatable body ; surrounding the terraqueous globe to a considerable height.

Air was considered by some of the ancients as an element ; but then, by element, they understood a different thing from what we do. See ELEMENTS.

It is certain, that air, taken in the popular sense, is far from the simplicity of an elementary substance ; though some of its properties and uses in a state of combination with various substances, from which it has been extricated by modern analysis, may entitle it to this appellation. Hence air may be distinguished into *proper* or *elementary*, and *vulgar* or *heterogeneous*.

AIR, *elementary*, or AIR *properly so called*, is a subtile, homogeneous, elastic fluid : the basis, or fundamental ingredient of the atmospherical air, and that which gives it the denomination.

In this sense, it likewise enters into the composition of most, or perhaps all bodies, existing in them under a solid form, deprived of its elasticity and most of its distinguishing properties, and serving as their cement, and the universal bond of nature ; but capable, by certain processes, of being disengaged from them, recovering its elasticity, and resembling the air of our atmosphere. See Hale's *Vegetable Statics*, chap. vi. See GAS.

The peculiar nature of this aerial matter we know but little of ; what authors have advanced concerning it being chiefly conjectural. We have no way of altogether separating it from the other matters with which in its purest state it is more or less combined, and consequently no way of ascertaining, with satisfactory evidence, its peculiar properties, abstractedly from those of other bodies.

Dr. Hook, and some others, maintain, that it is the same

same with their *æther*, or that fine, fluid, active matter, diffused through the whole expanse of the celestial regions; which coincides with Sir I. Newton's *subtile medium*, or spirit. In this view it is supposed to be a body *sui generis*, ingenerable, incorruptible, immutable, present in all places, and in all bodies.

Others, considering only its property of elasticity, which they account its essential and constituent character, suppose it to be mechanically producible; and to be no other than the matter of other bodies, so modified and altered, as to become permanently elastic. Sir Isaac Newton observes, that the particles of dense, compact, and fixed substances, cohering by a strong attractive force, are not separable without a vehement heat, or perhaps not without fermentation; and such bodies being at length rarified by such heat or fermentation, become true *permanent air*; and distinguishable from vapour, which is only *apparent*, or *transient air*, as is evident from the experiment with the æolipile. Optics, Qu. 31, p. 371, 372. ed. 3. See AIR, *atmosphærical*.

AIR, *vulgar* or *heterogeneous*, is a coalition of corpuscles of various kinds, constituting together one fluid mass, in which we live and move, and which we are continually receiving and expelling by respiration. The whole assemblage of this makes what we call the atmosphere; where this air, or atmosphere, terminates, there *æther* is supposed to commence; which is distinguished from air by its not making any sensible refraction of the rays of light, as air does.

Air, in this popular and extensive meaning of the term, is acknowledged by Mr. Boyle to be the most heterogeneous body in the universe. Boerhaave shews it to be an universal chaos, or colluvies, of all kinds of created bodies. Besides the matter of light or fire, which continually flows into it from the heavenly bodies, and probably the magnetic effluvia of the earth; whatever fire can volatilize is found in the air.

Hence, for instance, 1. The whole fossile kingdom must necessarily be found in it; for all of that tribe, as salts, sulphurs, stones, metals, &c. are convertible into fume, and thus capable of being rendered part of the air. Gold itself, the most fixed of all natural bodies, is found to adhere close to the sulphur in mines; and thus to be raised along with it. Mr. Boyle observes, that beside the saline effluvia of the common sort, such as the nitrous, vitriolic, marine, &c. there may be many compounded kinds of salts in the air, which we have not on earth, arising from different saline spirits, fortuitously meeting and mixing together. Thus, the glass windows of ancient buildings are sometimes observed to be corroded, as if they had been worm-eaten; though none of the simple salts above-mentioned have the faculty of corroding glass.

Sulphurs too must make a considerable ingredient of the air, on account of those many volcanos, grottos, caverns, and other spiracles chiefly affording that mineral, dispersed through the globe.

2. All the parts of the animal kingdom must also be in the air: for besides the copious effluvia continually emitted from their bodies, by the vital heat, in the ordinary process of perspiration; by means of which an animal, in the course of its duration, impregnates the air with many times the quantity of its own body; we find that any animal when dead, being exposed to the air, is in a certain time wholly incorporated with it.

3. As to vegetables, none of that class can be supposed wanting; since we know that all vegetables, by putrefaction, become volatile.

The associations, separations, attritions, dissolutions, and other operations of one sort of matter upon another, may likewise be considered as sources of numerous other neutral, or anonymous bodies, unknown to us.

4. Water is also diffused through the air in great abundance. Many familiar instances might be alledged to this purpose. A bottle of wine, when taken out of the cellar in the driest and hottest day of summer, will soon be covered with a dense vapour, which is water deposited by the air. The same appearance is observed on the outside of any metallic vessel, which, in warm weather, contains water cooled by ice or the solution of salt, or even spring water, which is some degrees colder than the air. For other facts of similar kind, see WATER.

Air, in this general sense, is one of the most considerable and universal agents in all nature; being concerned in the preservation of life, and the production of most of the phenomena relating to our world. Its properties and effects, including a great part of the researches and discoveries of the modern philosophers, have in a considerable degree been reduced to precise laws and demonstrations, in which form they make a very extensive and important branch of the mixed mathematics, called PNEUMATICS.

AIR, *mechanical properties and effects of*. The most considerable of these are its *fluidity*, *weight*, and *elasticity*.

I. *Fluidity*. That the air is a fluid, is evident from the easy passage it affords to bodies through it; as in the propagation of smells, and other effluvia, and the easy conveyance it affords to sounds: for these and similar effects prove it to be a body, whose parts give way to any force impressed, and, in yielding, are easily moved among themselves; which is the definition of a fluid. Besides, it is certain, that no condensation by pressure, nor any degree of cold that has ever yet been produced, natural or artificial, have been sufficient to deprive it of its fluidity. It is true, indeed, that real permanent air may be extracted from solid bodies, and may be also absorbed by them; and in this state it must be very much condensed: but under what form it exists in those bodies, or how its particles are combined together, the researches of philosophy and chemistry have not yet been able to explore.

They who, with the Cartesians, make fluidity to consist in a perpetual intestine motion of the parts, find that air answers also to that character: thus, in a darkened room, where the species of external objects are brought in by a single ray, they appear in a continual fluctuation; and thus even the more accurate thermometers are observed never to remain a moment at rest.

The cause of this fluidity of air is attributed by some later philosophers to the fire intermixed with it; without which, they imagine, the atmosphere would harden into a solid impenetrable mass. And hence, the greater the degree of fire, the more fluid, moveable, and pervious is the air: and thus, as the degree of fire is continually varying, according to the circumstances and position of the heavenly bodies, the air is kept in a continual reciprocation. See Buffon's Hist. Nat. Supp. vol. i. Hence, in a great measure, it is said, that on the tops of the higher mountains, the senses of smelling, hearing, &c. are found very feeble. The increased rarity of the air at a considerable height may account for this effect; but the above hypothesis is contradicted by the more sensible experience of cold: the air, near the surface of the earth, deriving greater heat from the reflected than from the direct rays of the sun.

II. *Weight or gravity.* Of this property of air the ancients were not altogether unapprised; though their sentiments on the subject were confused and unsatisfactory. Aristotle (de Cælo, lib. iv. c. 1. op. tom. i. p. 485.) observes, that all the elements, fire excepted, have weight; and he adds, that a bladder inflated with air, weighs more than when it is quite empty. Plutarch (de Placitis, lib. i. c. 12. tom. ii. p. 883.) and Stobæus (Eclog. Phys. lib. i. c. 17. p. 32. Ed. 1609.) quote Aristotle as teaching, that the weight of air is between that of fire and earth; and he himself, treating of respiration, (cap. vii. oper. tom. i. p. 722.) reports the opinion of Empedocles, who ascribes the cause of it to the weight of the air, which by its pressure insinuates itself with force into the lungs. Plutarch (de Placit. lib. iv. c. xxii. tom. ii. p. 903.) expresses, in similar terms, the opinion of Asclepiades on this subject; and represents him as saying, that the external air, by its weight, opened its way with force into the breast. Heron of Alexandria, in his treatise intitled *Spiritualia*, constantly applies the *elasticity* of the air to produce such effects as are sufficient to convince us that he well understood that property of it: and Ctesibius, admitting the principle of the air's elasticity, invented wind-guns, which have been considered as a modern contrivance. Philo of Byzantium (in Veter. Mathem. p. 77. Ed. Paris.) describes these curious machines, constructed upon the principle of the air's being capable of condensation. Seneca also (Quæst. Nat. lib. v. c. v. and vi.) was acquainted with the weight and elastic force of the air; for he describes the constant effort by which it expands itself when it is compressed, and affirms, that it has the property of condensing itself, and forcing its way through all obstacles that oppose its passage. See Dutens's Inquiry into the origin of the Discoveries attributed to the Moderns, p. 186. 1769. The followers of Aristotle, however, abandoned the sentiments of their master on this subject; and for many ages maintained a contrary doctrine. The effects which are now known to result from the weight and elasticity of the air, were for a long time attributed to the imaginary principle, called *fuga vacui*, or nature's abhorrence of a vacuum; and Galileo himself admitted the principle, though he assigned a limit to it, corresponding to the weight of a column of water 34 feet high. This distinguished philosopher, however, was well apprised of the weight of the air as a body; and, in his Dialogues, he points out two methods of demonstrating it, by weighing it in bottles. But the pressure of the air was discovered by his disciple, Torricelli. In the year 1643, it occurred to him, that whatever might be the cause by which a column of water, 34 feet high, is sustained above its level, the same force would sustain a column of any other fluid, which weighed as much as that column of water, on the same base; and hence he concluded, that quicksilver, being about 14 times as heavy as water, would not be sustained at a greater height than that of 29 or 30 inches. He then made the experiment, called after his name; and inferred from it, that the weight of the air incumbent on the surface of the external quicksilver, counterbalanced the fluid contained in the tube. By this experiment he not only proved, as Galileo had before done, that the air had weight, but that its weight was the cause of the suspension of water and quicksilver in pumps and tubes, and that the weight of the whole column of it was equal to that of a like column of quicksilver, 30 inches high, or of water 34 or 35 feet high; but he did not ascertain the weight of any particular quantity of it, as a gallon, or a cubic foot; nor its specific gravity to water, which had been done, though inaccurately, by Galileo. Torricelli's experiment was published at Warlaw, in Poland, by Valerianus

Magnus, as his own discovery; but from the letters of Roberval, it appears, that Torricelli's claim to priority is indisputable; and that neither Valerianus, nor Honoratus Fabri, to whom it has been ascribed so early as the year 1641, can justly dispute it with him. The first discovery of the weight and elasticity of the air has been lately ascribed to Jean Rey, who wrote in 1629, before Galileo, Torricelli, Des Cartes, and Paschal. His fourth and tenth essays have been cited in favour of his claims; but though he was apprized that compression augmented the weight of the air, and he seems to have believed, with Aristotle and others at a very ancient period, that air was heavy, yet the proofs which he alleges were not sufficient to convince the incredulity of the peripatetics. The Torricellian experiment, by which the fact was established, and which father Mersenne received an account of in 1644, was immediately communicated to the philosophers of France, and repeated in various ways by Messrs. Paschal and Petit: and this gave occasion to the ingenious treatise published by Paschal, at 23 years of age, intitled, "Experiences Nouvelles touchant la Vuide." Having, after some hesitation, adopted Torricelli's idea, and abandoned the principle of a *fuga vacui*, he devised several experiments for confirming it. One of these was to make a vacuum above the reservoir of quicksilver, in which case he found that it sunk to the common level; and he then engaged M. Perrier, his brother-in-law, to execute the famous experiment of Puy-de-Domme, who found that the height of the quicksilver half way up the mountain was less by some inches than at the foot of it; and that it was still less at the top. These facts incontrovertibly proved, that it was the weight of the atmosphere which counterpoised the quicksilver. Des Cartes had also just notions of the power of the air for sustaining fluids above their level, as appears by some letters about this time, and some years before; and in one of these he lays claim to the idea of the Puy-de-Domme experiment. See Cartesii Opera, tom. ii. p. 243, 246.

The experiment of Paschal was repeated in various parts of the world; and particularly in 1653, by Dr. Power, in England; and in 1661, by Mr. Sinclair, professor of philosophy at Glasgow, in Scotland.

That the air is heavy, follows from its being a body; weight being an essential property of matter. And that it is a body, is evident from its excluding all other bodies out of the space it possesses; for if a glass jar be inverted into a vessel of water, the air, of which it is full, will allow but little water to enter into it. But we have many arguments to the same purpose from sense and experiment: thus, the hand, applied on the orifice of a vessel empty of air, soon feels the load of the incumbent atmosphere. Thus, glass vessels, exhausted of their air, are easily crushed to pieces by the weight of the air without. So, two small hollow segments of a sphere, four inches in diameter, exactly fitting each other, being emptied of air, are pressed together with a force equal to 188 pounds, by the weight of the ambient air; and that they are kept together by the pressure of the air is evident, by suspending them in an exhausted receiver, where they will separate of themselves. Farther, if a tube, close at one end, be filled with mercury, and the other end immersed in a basin of the same fluid, and thus erected, the mercury in the tube will be suspended at the height of about 30 inches above the surface of that in the basin. The reason of which suspension is, that the mercury in the tube cannot fall lower without raising that in the basin; which being pressed down by the weight of the incumbent atmosphere cannot give way, unless the weight of the mercury in the tube exceeds that of the air out of

it. That this is the case, is evident; because, if the whole apparatus be included in the receiver of an air pump, the mercury will fall in proportion as the air is exhausted; and on gradually letting in the air again, the mercury reascends to its former height. This makes what is usually called the *TORRICELLIAN experiment*.

To say no more, we can actually weigh air; for a vessel, full even of common air, is found, by a very nice balance, to weigh more than when the air is exhausted; a quart of air weighing about 17 grains; and the effect is proportionably more sensible, if the same vessel be weighed full of condensed air, and more especially in a receiver void of air.

The weight of air is continually varying, according to the different degree of heat and cold, and the concurrence of other causes. Pascal observed it in France; and Des Cartes in Sweden, in 1650. Mr. Boyle, and others, observed it in England, in 1656. Some observers noticed, that it was generally greatest in the night and in winter; and that its variations were most considerable during winter, and in the northern regions. Hence arose the application of the *BAROMETER* to the uses of a *WEATHER-GLASS*. Riccioli estimates the weight of air to that of water, to be as 1 to 1000; Merkenius as 1 to 1300, or 1 to 1356; Lana, as 1 to 640; Galileo only makes it as 1 to 400. Mr. Boyle, by a more accurate experiment, found it about London, as 1 to 938; and thinks, all things considered, the proportion of 1 to 1000 may be taken as a medium; for there is no fixing any precise ratio, since not only the air, but the water itself, is continually varying. Besides, experiments made in different places necessarily vary, on account of the different heights of the places, the seasons of making the experiment, and the different densities of air corresponding to these circumstances. It must be added, however, that by experiments made since, before the Royal Society, the proportion of air to water was, first, found as 1 to 840; then, as 1 to 852; and a third time, as 1 to 860. Phil. Trans. N° 181. And lastly, by a very simple and accurate experiment of Mr. Hauksbee, the proportion was settled, as 1 to 885. Phys. Mechan. Exper. But these experiments being all made in the summer months, when the barometer was 29½ inches high, Dr. Jurin thinks, that at a medium between heat and cold, when the barometer is 30 inches high, the proportion between the two fluids may be taken as 1 to 800; which agrees with the observation of the honourable Mr. Cavendish, the thermometer being at 50°, and the barometer at 29½ inches. Phil. Trans. vol. lvi. p. 152.

Sir George Shuckburgh, (Phil. Trans. vol. lxvii. p. 560.) by a very accurate experiment, found it as 1 to 836; the barometer being at 29,27 inches, and the thermometer at 53°; and the comparative gravity of quicksilver to air, as 11364,6 to 1. The medium of all these is about one to 832 or 833, when reduced to the pressure of 30 inches of the barometer, and the mean temperature 55° of the thermometer. Upon the whole, it may be concluded, that when the barometer is at 30 inches, and the thermometer at the mean temperature of 55°, the density or gravity of water is to that of air as 833 ⅓ to 1; that is, as $\frac{1250}{3}$ to 1, or as

2500 to 3; and for any changes in the height of the barometer, the ratio varies proportionally; and also that the density of the air is altered by the $\frac{1}{447}$ th part, for every degree of the thermometer above or below temperate. This number, which is a very good medium, having the fraction $\frac{1}{447}$, gives exactly $1\frac{1}{447}$ of an ounce for the mean weight of a cubic foot of air; the weight of the cubic foot of water

being just 1000 ounces avoirdupois, and that of quicksilver equal to 13600 ounces.

Air, then, being heavy and fluid, the laws of its gravitation, or pressure, may be inferred to be the same as those of other fluids; and consequently its pressure must be proportional to its perpendicular altitude. This is also confirmed by experiment. For removing the Torricellian tube to a more elevated place, where the incumbent column of air is shorter, a proportionably shorter column of mercury is sustained; and that nearly at the rate of 100 feet for $\frac{1}{18}$ th of an inch of quicksilver. On this principle depend the structure and office of the *BAROMETER*.

From hence, also, it follows, that the air, like all other fluids, must press equally every way. This is confirmed by observing, that soft bodies sustain this pressure without any change of figure, and brittle bodies without breaking; though the pressure upon them be equal to that of a column of mercury thirty inches high, or a column of water of thirty-two or somewhat more feet. It is obvious, that no other cause can preserve such bodies unchanged, but the equable pressure on all sides, which resists as much as it is resisted. And hence, upon removing or diminishing the pressure on one side only, the effect of the pressure is soon perceived on the other. For the quantity and effect of this pressure of the atmosphere on the human body, and on the surface of the earth, and the laws of different heights, see *ATMOSPHERE*.

From the *gravity* of the air, considered in connection with its *fluidity*, several of its uses and effects may be easily deduced.

1. By means of its weight, &c. it closely invests the earth, with all the bodies upon it; and constricts and binds them down with a force amounting, according to the computation of M. Pascal, to 2232 pounds weight upon every square foot, or upwards of 15 pounds upon every square inch. Hence it prevents, *e. gr.* the arterial vessels of plants and animals from being too much distended by the impetus of the circulating juices, or by the elastic force of the air, so plentifully contained in the blood.—Thus we see, in the operation of cupping, that, upon a diminution of the pressure of the air, the parts of the body grow tumid; which necessarily alters the manner of the circulation through the capillaries, &c.

The same cause hinders the juices from ousing and escaping through the pores of their containing vessels: this is experienced by such as travel up high mountains, who, in proportion as they ascend, find themselves more and more relaxed; and at length become subject to a spitting of blood, and other hæmorrhages; because the air doth not sufficiently constrict the vessels of the lungs. Similar effects are observed in animals that are enclosed under the receiver of the air-pump, who, as the air is taken from them, pant, swell, vomit, and discharge their urine and excrements. See *VACUUM*.

2. The weight of the air promotes the mixture of contiguous fluid bodies. Hence many liquids, as oils and salts, which readily and spontaneously mix in air, remain, on the removal of it, in a state of separation.

3. This gravity of air does in some cases determine the action of one body above another.

4. To the same principle are chiefly owing our winds, which are only air put in motion by some alteration in its equilibrium. It is the weight of the air that causes the clouds and vapours to float in it.

III. *Elasticity*—or a power of yielding to an impression by contracting its dimensions; and upon removing or diminishing the impressing cause, of returning to its former space or figure, is another quality of air. This elastic

force has been long accounted the distinguishing property of air; the other properties hitherto enumerated being common to it with other fluids; though, from late experiments, it appears more than probable, that the capacity of being compressed and expanded is not peculiar to air. See WATER and COMPRESSION.

This property of air has been long known, and was ascertained by some experiments of lord Bacon, who, upon this principle, constructed his *vitrum calendare*, the first thermometer. Bacon. Nov. Organ. lib. ii. aph. 13.

Of this power we have numerous proofs.—Thus, a blown bladder being squeezed in the hand, we find the included air sensibly resist; so that, upon ceasing to compress, the cavities or impressions, made in its surface, are readily expanded again, and filled up.

On this property of elasticity, the structure and office of the AIR-PUMP depend.

Every particle of air always exerts this nifus, or endeavour to expand, and thus strives against an equal endeavour of the ambient particles, whose resistance happening by any means to be weakened, it immediately diffuses itself into an immense extent. Hence it is, that thin glass bubbles, or bladders filled with air, and exactly closed, being included in the exhausted receiver of an air-pump, burst by the force of the included air. So a bladder quite flaccid, containing only the smallest quantity of air, swells in the receiver, and appears quite full. The same effect is also found by carrying the flaccid bladder to the top of a high mountain. This experiment shews, that the elasticity of air is different from that of solid bodies: after these have been compressed, they only resume the figure which they had lost; whereas air, when the compressing force is removed, not only dilates, but occupies a much greater space than it did before; nor is it easy to assign the limits of its expansion. From some experiments of Col. Roy (Phil. Trans. vol. 67. p. 708.) it would seem, that the particles of air may be so far removed from one another, by the diminution of pressure, as to lose a very great part of their elastic force. It also appears that the elastic force of common air is greater than when its density is considerably augmented or diminished by an addition to, or subtraction from, the weight with which it is usually loaded; a fact which contradicts the experience of Boyle, Mariotte, and others. These experiments also shew, that the elastic force of moist air is greatly superior to that of dry air; in some cases the total expansion of the former was more than four times that of the latter.

It has been questioned among philosophers, whether this elastic power of the air is capable of being destroyed or diminished. Mr. Boyle made several experiments, with a view to discover how long air, brought to the greatest degree of expansion to which he could reduce it in his air-pump, would retain its spring; and could never observe any sensible diminution. De Sauguliers found that air, after having been enclosed for half a year in a wind gun, had lost none of its elasticity; and Roberval, after preserving it in the same manner for sixteen years, observed, that its expansive projectile force was the same as if it had been recently condensed. Nevertheless, Mr. Hauksbee concludes, from a later experiment, that the spring of the air may be so disturbed by a violent pressure, as to require some time to return to its natural tone. Dr. Hales inferred, from a number of experiments, that the elasticity of the air is capable of being impaired and diminished by a variety of causes, and of being actually destroyed, so that it is reduced to a fixed state. Hence he also concludes, that elasticity is not an essential immutable property of the particles of air; and that the atmosphere is a chaos, consisting not only of elastic, but also of unelastic air-

particles, which copiously float in it. Statical Essays, vol. i. p. 216.

The weight or pressure of the air, it is obvious, has no dependence on its elasticity; but would be the same, whether the air has such a property or not. But the air, being elastic, is necessarily affected by the pressure, which reduces it into such a space, as that the elasticity which re-acts against the compressing weight, is equal to that weight. Indeed, the law of this elasticity is, that it increases as the density of the air increases; and the density increases as the force increases by which it is pressed. Now, there must necessarily be a balance between the action and re-action; i. e. the gravity of the air, which tends to compress it, and the elasticity of the air, which endeavours to expand it, must be equal. And the elasticity of the air not very different from its natural state, being as the density, will of course be inversely as the space which it occupies.

Hence the elasticity increasing, or diminishing, universally, as the density increases or diminishes, i. e. as the distance between the particles diminishes, or increases, it is no matter whether the air be compressed and retained in such space, by the weight of the atmosphere, or by any other means; it must endeavour, in either case, to expand with the same force. And hence if air near the earth be pent up in a vessel, so as to cut off all communication with the external air, the pressure of the inclosed air will be equal to the weight of the atmosphere. Accordingly, we find mercury sustained to the same height, by the elastic force of air inclosed in a glass vessel, as by the whole atmospherical pressure.

On the same principle air may be artificially condensed; and hence the structure of the AIR-gun.

Although it may be admitted as a general principle, that the density of the air is proportional to the force by which it is compressed, as the experiments of Mr. Boyle and Mr. Mariotte have evinced; yet in the case of condensed air, the rule will not be strictly applicable. When air is very forcibly compressed, so as to be reduced to $\frac{1}{4}$ th of its ordinary bulk, it makes a greater resistance, and requires a stronger force to compress it than the above principle allows. Hence it appears probable, that the particles of air cannot, by any possible pressure, be brought into perfect contact, or form a solid mass; and therefore that the degree of condensation has its limit. Thus also in very high degrees of rarefaction, the elasticity is decreased rather more than in an exact proportion to the weight or density of the air; whence it may be concluded, that there is a limit to its rarefaction or expansion, so that it cannot be expanded to infinity. Nevertheless, the utmost limits to which air of the density which it possesses at the surface of the earth, is capable of being compressed, have not been ascertained. Mr. Boyle reduced it at one time to the $\frac{1}{14}$ th part, and at another to the $\frac{1}{40}$ th part of its natural space. (Works, vol. iii. p. 507.) Dr. Halley says, that he has seen it compressed so as to be 60 times denser than in its natural state, which is farther confirmed by Mr. Papin, and M. Huygens. Dr. Hales (Stat. Exp. vol. ii. p. 342, &c.) by means of a press, condensed it 38 times; and by freezing water in an iron ball, or globe, into 1522 times less space than it naturally occupies: in which state its density or specific gravity must be nearly double that of water; and as water is very slightly compressible, the particles of air must be in their nature different from those of water; since it would otherwise be impossible to reduce air to a bulk 800 times less than that which it occupies in its natural state.

However, Dr. Halley has asserted, in the Philosophical Transactions, (Abf. vol. ii. p. 17.) that from the experi-

ments made at London, and by the Academy del Cimento at Florence, it might be safely concluded, that no force whatever is able to reduce air into 800 times less space than that which it naturally possesses on the surface of our earth. In answer to which, M. Amontons, in the Memoirs of the French Academy, maintains, that there is no affixing any bounds to its condensation; that greater and greater weights will still reduce it into less and less compass; that it is only elastic in virtue of the fire which it contains; and that as it is impossible ever absolutely to drive all the fire out of it, it is impossible ever to make the utmost condensation.

The elasticity of the air exerts its force equally in all directions; and when released from the force that compresses it, it assumes a spherical figure in the interstices of the bodies that contain it. By exhaling the air from liquors placed under the receiver of an air-pump, the bubbles that gradually arise and are enlarged in size, retain their round figure. Such are also the bubbles that discharge themselves from a plate of metal immersed in a fluid in the same circumstances. On this account large glass globes are always formed of a spherical shape by blowing air through an iron tube into a piece of melted glass at the end of the tube.

The dilatation of the air by virtue of its elastic force, is found to be very surprising; and yet Dr. Wallis suggests, that we are far from knowing the utmost of which it is capable. In several experiments made by Mr. Boyle, it dilated first into 9 times its former space; then into 31 times; then into 60; and then into 150. Afterwards, it was brought to dilate into 8000 times its first space; then into 10,000, and even at last into 13,679 times its space; and this altogether by its own expansive force, without the help of fire. Boyle's Works by Birch, vol. i. p. 21, 22. vol. iii. p. 498, 499.

On this depend the structure and use of the MANOMETER. Hence it appears, that the air we breathe near the surface of the earth is compressed by the weight of the superincumbent column into at least the 13679th part of the space it would possess *in vacuo*. But if the same air be condensed by art, the space it will take up when most dilated, to that it possesses when condensed, will be, according to the same author's experiments, as 550,000 to 1.

We hence see how wild and erroneous the observation of Aristotle was, that air, rendered ten times rarer than before, changes its nature, and becomes fire.

It has generally been supposed, that air expands $\frac{1}{800}$ with each degree of the thermometer, commencing from the mean temperature 55°; and upon this principle tables have been computed by astronomers for correcting their mean refractions; but Sir George Shuckburgh allows at this temperature an expansion of $\frac{1}{7}$ for 1°. Phil. Trans. v. 67. p. 564. Mr. Hawksbee observed, that a portion of air, included in a glass tube, when the temperature was at the freezing point, formed a volume which was to that of the same quantity of air in the greatest heat of summer in England as 6 to 7. Moist air has been expanded into more than 12 times the space occupied by it in its freezing state; and Mercurius by means of the æolipile expanded it into more than 70 times its natural bulk. Muschenb. Introd. ad. Phil. Nat. tom. ii. p. 884. 4to.

M. Amontons, and others, we have already observed, attribute the rarefaction of the air wholly to the fire contained in it; and therefore, by increasing the degree of heat, the degree of rarefaction may be carried still farther than its spontaneous dilatation. Air is expanded $\frac{1}{4}$ of its bulk by boiling water. Hist. Acad. Sc. 1699.

Dr. Hales found that the air in a retort, when the bottom of the vessel was just beginning to be red hot, was expanded

through twice its former space, and in a white, or almost melting heat, it occupied thrice its former space; but Mr. Robins found, (New Principles of Gunnery, ch. 1. prop. 5. p. 12.) that air was expanded by the heat of iron, just beginning to be white, to four times its former bulk. Thus we account for the apparent inflation of a flaccid bladder, when it is warmed by the fire, and on this principle depend the structure and office of the THERMOMETER, and also the formation and ascent of air-balloons. See AEROSTATION.

M. Amontons first discovered that air will expand, in proportion to its density, with the same degree of heat. On this foundation, the ingenious author has a discourse, to prove, 'that the spring and weight of the air, with a moderate degree of warmth, may enable it to produce even earthquakes, and other of the most vehement commotions of nature.'

According to the experiments of this author, and M. de la Hire, a column of air on the surface of the earth, 36 fathoms high, is equal in weight to three lines depth of mercury; and it is found, that equal quantities of air possess spaces reciprocally proportioned to the weights with which they are pressed; the weight of the air, therefore, which would fill the whole space possessed by the terrestrial globe, would be equal to a cylinder of mercury, whose base is equal to the surface of the earth, and its height containing as many times three lines, as the atmospherical space contains orbs equal in weight to 36 fathoms of that wherein the experiment was made.—Hence, taking the density of all bodies, *e. gr.* gold, whose gravity is about 14,630 times greater than that of air in our orb, it is easy to compute, that this air would be reduced to the same density as gold, by the pressure of a column of mercury 14,630 times 28 inches high, *i. e.* 409,640 inches, since the bulks of air, in that case, would be in the reciprocal ratio of the weights by which they are pressed. These 409,640 inches, therefore, express the height at which the barometer must stand, where the air would be as heavy as gold, and the number 2,448,333 lines, the thickness to which our column of 36 fathoms of air would be reduced in the same place.

Now, we know, that 43,528 fathoms, which is the depth, where the above pressure, and consequent reduction take place, are only the 74th part of the semidiameter of the earth; and, therefore, beyond that depth, whatever matter exists, it must be heavier than gold. It is not improbable, therefore, that the remaining sphere of 6,451,538 fathoms diameter may be full of dense air, heavier by many degrees than the heaviest bodies which we know. Hence, again, as it is proved, the more air is compressed the more does the same degree of fire increase the force of its spring, and render it capable of a proportionably greater effect; we may infer, that a degree of heat, which in our orb can only produce a moderate effect, may have a very violent one in such lower orb; and that, as there may be many degrees of heat in nature, beyond that of boiling water, it is probable there may be some, whose violence, thus assisted by the weight of the air, may be sufficient to tear asunder the solid globe. Mem. de l'Acad. an. 1703. See EARTHQUAKES.

This elastic property of air is supposed by many philosophers to depend on the figure of its corpuscles, which they apprehend to be ramous; some maintain that they are so many minute *foculi*, resembling fleeces of wool; others conceive them rolled up like hoops, and curled like wires, or shavings of wood, or coiled like the springs of watches, and endeavouring to restore themselves in virtue of their texture: so that to produce air, must be to produce such a figure and disposition of parts; and those bodies only are

proper subjects, which are susceptible of such disposition ; which fluids, from the smoothness, roundness, and slipperiness of their parts, are not.

But Sir Isaac Newton (*Optics*, p. 371.) explains the matter otherwise ; such a texture, he thinks, by no means sufficient to account for that vast power of elasticity observed in air, which is capable of diffusing itself into above a million of times more space than it before possessed.—But, as all bodies are shewn to have an attractive and repelling power ; and as both these are stronger in bodies, the denser, more compact, and solid they are ; hence it follows, that when by heat, or any other powerful agent, the attractive force is surmounted, and the particles of the body separated so far as to be out of the sphere of attraction ; the repelling power which then commences makes them recede from each other with a strong force proportionable to that with which they before cohered ; and thus they become permanent air. And he has proved, that particles, endeavouring to recede from each other with forces reciprocally proportional to the distance between their centres, will compose an elastic fluid, whose density shall be proportional to its compression. Hence, says the same author, it is, that as the particles of permanent air are grosser, and rise from denser bodies, than those of transient air, or vapour, true air is more ponderous than vapour ; and a moist atmosphere is lighter than a dry one.

The elastic power of the air above illustrated and evinced, is the second great source of the effects of this important fluid. By this property, it insinuates itself into the pores of bodies, and by possessing this prodigious faculty of expanding, which is so easily excited, it must necessarily put the particles of bodies into which it insinuates itself into perpetual oscillations. Indeed, the degree of heat, and the air's gravity and density, and consequently its elasticity and expansion, never remaining the same for the least space of time, there must be an incessant vibration, or dilatation and contraction of all bodies.

We observe this reciprocation in several instances, particularly in plants, the tracheæ, or air-vessels of which perform the office of lungs ; for the contained air alternately expanding and contracting, as the heat increases or is diminished, by turns compresses the vessels, and eases them again : and thus promotes a circulation of their juices. See *AIR-vessels*.

Hence, we find, that no vegetation nor germination will proceed *in vacuo*. Indeed beans have been observed to grow a little tumid therein ; and this has led some to attribute that to vegetation, which was really owing to no other cause than the dilatation of the air within them.

The air is very instrumental in the production and growth of vegetables, not only by invigorating their several juices, while in an elastic active state, but also by greatly contributing in a fixed state to the union and firm connection of their several constituent parts, and by supplying them with that food or pabulum, which contributes to their growth.

From the same cause it is, that the air contained in bubbles of ice, by its continual action, bursts the ice ; and thus also, as well as by the expansion of freezing fluids, glasses and other vessels frequently crack, when their contained liquors are frozen. Thus also, entire columns of marble sometimes cleave in the winter time, from some little bubble of included air's acquiring an increased elasticity : and to this it is owing, that few stones will bear to be heated by the fire without cracking by the expansive force of the air confined within their pores. From the same principle arise *putrefaction* and *fermentation* ; neither of which will proceed, even in the best disposed subjects, *in vacuo*.

Since we find such great quantities of elastic air, generated in the solution of animal and vegetable substances, a good deal must constantly arise from the dissolution of these elements in the stomach and bowels, which is much promoted by it : and respiration, and even animal life, depend in a great measure upon the air.

In reality, all natural corruption and alteration seem to depend on air ; and metals, particularly gold, only seem to be durable and incorruptible, in virtue of their not being pervious to air.

Air, effects of the different ingredients of. Air not only acts by its common properties of gravity and elasticity, but there are numerous other effects, arising from the peculiar ingredients of which it consists.

Thus, 1. It not only dissolves and attenuates bodies by its pressure and attrition, but as a *chaos* containing all kinds of menstrea, and consequently possessing powers for dissolving all bodies. It is known that iron and copper readily dissolve, and become rusty in air, unless well defended with oil. Boerhaave assures us, that he has seen pillars of iron so reduced by air, that they might be crumbled to dust between the fingers ; and as for copper, it is converted by the air into a substance much like the verdigrise produced by vinegar.

Mr. Boyle relates, that in the southern English colonies the great guns rust so fast, that after lying in the air for a few years, large cakes of *crocus martis* may be separated from them. Acolta adds, that in Peru the air dissolves lead, and considerably increases its weight. Yet gold is generally esteemed indissoluble by air ; being never found to contract rust, though exposed to it ever so long. In the laboratories of chemists, however, where *aqua regia* is prepared, the air becoming impregnated with an unusual quantity of this menstruum, gold contracts a rust like other bodies.

Stones also undergo the changes incident to metals.—Thus, Purbeck stone, of which Salisbury cathedral consists, is observed gradually to become softer, and to moulder away in the air ; and Mr. Boyle gives the same account of Blackington stone. He adds, that air may have a considerable operation on vitriol, even when a strong fire could act no further upon it. And he has found, that the fumes of a corrosive liquor work more suddenly and manifestly on a certain metal, when sustained in the air, than the menstruum itself did, which emitted fumes on those parts of the metal which it covered ; referring to the effects of the effluvia of vinegar on COPPER.

The dissolving power of air is increased by heat, and by other causes. It combines with water ; and, by access of cold, deposits part of the matter which was kept dissolved in it, by a greater degree of heat. Hence the water, by being deposited and condensed upon any cold body, such as glass, &c. in windows, forms fogs, and becomes visible. Air, likewise, has been supposed, by means of its dissolving power, to accelerate EVAPORATION and DISTILLATION.

2. Air volatilizes fixed bodies. Thus, sea-salt, being first calcined, then fused by the fire, and when fused, exposed to the air to liquify ; when liquified set to dry, and then fused again, repeating the operation, will, by degrees, be almost wholly evaporated ; nothing but a little earth remaining. Helmont mentions it as an arcanum in chemistry, to render fixed salt of tartar volatile ; but this is easily affected by air alone : for, if some of this salt be exposed to the air, in a place replete with acid vapours, the salt draws the acid to itself, and when saturated with it, is volatile.

3. Air also fixes volatile bodies. Thus, though spirit

of nitre, or aquafortis, readily evaporates by the fire: yet if there be any putrescent urine near the place, the volatile spirit will be fixed, and fall down in form of AQUA SECUNDA.

4. Air brings many quiescent bodies into action; i. e. excites their latent powers. Thus, if an acid vapour be diffused through the air, all the bodies of which that is the proper menstruum, being dissolved by it, are brought into a state proper for action.

In the various operations of chemistry, air is a very necessary and important agent, the result of particular processes depending on its presence or absence, on its being open or enclosed. Thus the parts of animals and vegetables can only be calcined in open air; in close vessels they never become any other than black coals. And these operations are effected by the changes to which the air is liable. Many instances might be alledged to this purpose. Let it suffice to observe, that it is very difficult to procure oil of sulphur, *per campanam*, in a clear dry atmosphere; but in thick moist air it may be obtained with greater ease, and in larger quantities. So pure well-fermented wine, if it be carried to a place where the air is replenished with the fumes of new wine, then fermenting, will begin to ferment afresh.

The changes in the air arise from various causes, and are observable not only in its mechanical properties, such as gravity, density, &c. but in the ingredients that compose it. Thus, at Fahlun, in Sweden, noted for copper-mines, the mineral exhalations affect the air in such a manner, as to discolour the silver coin in purses; and the same effluvia change the colour of brass. In Carniola, Campania, &c. where are mines of sulphur, the air sometimes becomes very unwholesome, which occasions frequent epidemic diseases, &c.

The effluvia of animals also have their effect in varying the air, as is evident in contagious diseases, plagues, murrains, and other mortalities, which are spread by an infected air.

The sudden and fatal effect of noxious vapours has generally been supposed to be principally, if not wholly, owing to the loss and waste of the *vivifying spirit of air*. But Dr. Hales attributes this effect to the loss of a considerable part of the *air's elasticity*, and to the grossness and density of the vapours with which the air is charged. He found, by an experiment made on himself, that the lungs will not rise and dilate as usual, when they draw in such noxious air, the elasticity of which has been considerably diminished. For having made a bladder very supple by wetting it, and then cutting off so much of the neck as would make a hole wide enough to admit the biggest end of a large fuset, to which the bladder was bound; and then having blown the bladder, he put the small end of the fuset into his mouth, and, at the same time, pinched his nostrils so close, that no air might pass that way, and he could only breathe to and fro the air contained in the bladder, which, with the fuset, contained seventy-four cubic inches. In less than half a minute, he found a considerable difficulty in breathing; and at the end of a minute, the bladder was become so flaccid, that he could not blow it above half full, with the greatest expiration which he could make; and at the same time, he could plainly perceive that his lungs were much fallen, in the same manner as when we breathe out of them all the air we can at once. Hence he concluded, that a considerable quantity of the elasticity of the air was destroyed; and that when the suffocating quality of the air was the greatest, it was with much difficulty that he could dilate his lungs in a very small degree. From this, and several other experiments, he inferred, that the life of animals is preserved rather by the

elastic force of the air acting on their lungs than by its vivifying spirit; and that candles and matches cease to burn, after having been confined in a small quantity of air, not because they have rendered the air effete by consuming its vivifying spirit, but because they have discharged a great quantity of acid fuliginous vapours, which partly destroy its elasticity, and retard the elastic motion of the remainder. He likewise found, that air, which passed through cloths dipped in vinegar, could be breathed to and fro as long again as the like quantity of air, which was not thus purified; so that sprinkling the decks of ships with vinegar may refresh the air; and this is confirmed by experience. But where the corruption of the air is much greater, as in close prisons, &c. nothing can be an adequate and effectual remedy but a *VENTILATOR*. He observed, likewise, that air is not disqualified for respiration merely by the additional moisture which it receives, but by some bad quality in that moisture. See his *Statical Essays*, vol. i. p. 250. vol. ii. p. 320, &c.

Dr. Priestley observes, that, when animals die upon being put into air, in which other animals have died, after breathing in it as long as they could, it is plain that the cause of their death is not the want of any *pabulum vite*, which has been supposed to be contained in the air; but because the air is impregnated with something stimulating to their lungs; for they almost always die in convulsions, and are sometimes affected so suddenly, that they are irrecoverable after a single inspiration. And he has found the same effect from many other kinds of noxious air. He concludes, from subsequent experiments, that the air becomes phlogisticated in its passage through the lungs, by means of the blood. *Experiments and Observations on Air*, vol. i. p. 71. vol. ii. p. 31. vol. iii. p. 55. See *AZOT, BLOOD, and RESPIRATION*.

Vegetables likewise produce a change in the state of the air. Thus when a great part of the clove trees, which grow so plentifully in the island of Ternate, was felled at the solicitation of the Dutch, in order to heighten the value of that fruit, such a change ensued in the air, as shewed the salutary effects of the effluvia, or rather of the vegetation of the clove-trees, and their blossoms; the whole island soon after they were cut down, being exceeding sickly. See *AZOT*.

The air is also liable to alterations from the season of the year. Thus few subterraneous effluvia are emitted in the winter, because the pores are locked up by the frost, or covered by snow; the subterraneous heat being at work, and preparing a heat to be discharged in the ensuing spring. Again, from the winter solstice to the summer solstice, the sun's rays become more and more perpendicular, and consequently their impulse on the earth's surface more powerful; so that the glebe, or soil, is more and more relaxed, softened, and putrescent, till he arrives at the tropic; where, with the force of a chemical agent, he resolves the superficial parts of the earth into their constituent principles, water, oil, salt, &c. which are all swept away into the atmosphere.

The height and depth of the air produce a farther alteration; the exhalations not rising high enough in any great quantity, to ascend above the tops of high mountains.

From some experiments with air-balloons, it has been proved, that the air of the higher regions is more impure than that at the surface of the earth; which is reasonably ascribed to the oxygen supplied by vegetation to the lower and contiguous stratum of air.

Nor must drought and moisture be denied their share, in varying the state of the atmosphere; in Guinea, the heat, with the moisture, conduces so much to putrefaction, that the purest white sugars are often full of maggots; and their

drugs soon lose their virtue; and many of them grow verminous: it is added, that in the island of St. Jago, they are obliged to expose their sweet-meats daily to the sun, in order to exhale the moisture contracted in the night, which would otherwise occasion them to putrefy.

On this principle depend the structure and use of the **HYGROMETER**.

For the refracting power of air; see **REFRACTION**.

After all, some of our more curious and penetrating naturalists have observed certain effects of air, which do not appear to follow from any of the properties, or materials above recited. In this view, Mr. Boyle has composed a treatise of suspicions about some unknown properties of the air. The phenomena of fire and flame in *vacuo* seem, according to him, to argue some unknown vital substance, diffused through the air, on account of which that fluid becomes so necessary to the subsistence of flame. Buffon supposes that air is necessary to the subsistence of fire, because it is most adapted to acquire that expansive motion, which is the principal property of fire. On this account fire combines with air; in preference to any other substance, and in a more intimate manner, as being of a nature most nearly approaching to its own; and therefore air is the proper aliment and most powerful assistant of fire. Hist. Nat. Supp. vol. i.

According to Dr. Priestley, the air is a menstruum for the phlogiston emitted by burning bodies; which must cease to burn when that menstruum is saturated with it. And he accounts in the same manner for the suffocation of animals in a confined space. When the phlogiston, emitted by burning bodies and breathing animals, can no longer be absorbed by the ambient air, both life and flame are extinguished. Exp. and Obs. &c. vol. i.

For the modern hypothesis, with regard to this subject, see **COMBUSTION** and **PHLOGISTON**.

Thus we find, that many causes combine to produce very considerable alterations in the state of the air, whereby it becomes less fit for respiration, and other purposes of nature; and if there were no provision for restoring its salubrity, it must, in time, become universally injurious and fatal. Dr. Priestley, in the course of his inquiries on this subject, has discovered the great restoratives, which are provided for this purpose. One of these is vegetation. In order to ascertain this fact, he put a sprig of mint, in a vigorous state, under a glass jar, inverted in water; and he found, contrary to his expectation, that this plant not only continued to live, though in a languishing way, for two months; but that the confined air was so little corrupted by the effluvia of the mint, that it would neither extinguish a candle, nor kill a small animal, which he conveyed into it. He found, likewise, that air, vitiated by a candle left in it till it was burnt out, was perfectly restored to its quality of supporting flame, after another sprig of mint had vegetated in it for some time. And, in order to shew that the aromatic flavour of the plant had no share in producing this effect, he observed, in a variety of other experiments, that vegetables of an offensive smell, and even such as had scarce any smell at all, but were of a quick growth, proved the best for this purpose. Nay, more, the virtue of growing vegetables was found to be an antidote to the baneful quality of air, corrupted by animal respiration and putrefaction; and he infers from a number of similar facts, that the injury, which is continually done to the atmosphere, by the respiration of so many animals, and the putrefaction of such masses of both vegetable and animal matter, is, in part at least, repaired by the vegetable creation; and notwithstanding the prodigious mass of air that is corrupted daily by the

above mentioned causes; yet, if we consider the immense profusion of vegetables upon the face of the earth, growing in places suited to their nature, and consequently at full liberty to exert all their powers, both inhaling and exhaling, it can hardly be thought, that the remedy is not adequate to the evil. Dr. Franklin, in a reflection on this discovery, expresses his hope, that it will give some check to the rage of destroying trees that grow near houses, which has accompanied our late improvements in gardening, from an opinion of their being unwholesome; adding, from long observation, that there is nothing unhealthy in the air of woods; "since the Americans leave their country habitations in the midst of woods, and no people on earth enjoy better health, or are more prolific." Dr. Priestley has since discovered that light is necessary to enable plants to purify air; however, pure air is not produced by light or plants, but only by the purification of the impure air to which the plants have access. Obs. and Exp. on Air, vol. v. p. 18, 24, &c.

The sea, and other large bodies of water, are the second resource, which nature has provided for restoring the salubrity of corrupted air. Dr. Priestley found, that all kinds of noxious air were restored by continued agitation in a trough of water; the noxious effluvia being first imbibed by the water, and thereby transmitted to the common atmosphere. And he hence concludes, that the agitation of the sea, and of large lakes and rivers, must be highly useful for the purification of the atmosphere; the putrid matter being absorbed by the water, and imbibed by marine, and other aquatic plants, or applied to purposes yet unknown. Exp. and Obs. vol. i. sect. 2. and 4.

This ingenious philosopher apprehends, that the agitation of water, and the vegetation of plants, purify noxious air, by absorbing part of the phlogiston with which it is loaded; and that this phlogistic matter is the most essential part of the food and support of both vegetable and animal bodies. Ib. vol. i. p. 138, 139.

Dr. Priestley, improving upon the experiments and investigations of Boyle, Hales, Brownrigg, Black, Macbride, Cavendish, and others, has discovered many species of air, extracted by various processes from different kinds of substances; of which a summary account will be given in the course of this work. See also his curious and valuable Experiments and Observations on different Kinds of Air, in five volumes. And for a compendium of the history of discoveries on this subject, Lavoisier's Essays Physical and Chemical, vol. i.

For the resistance of the air, see **RESISTANCE**.

AIR, undulation of. See **SOUND** and **UNDULATION**.

AIR, in Chemistry. See **GAS**.

AIR, *Atmospheric, common air, Gas atmospherique*, Fr. Atmospheric air does not appear to have been the subject of chemical investigation before the time of Boyle; for though Aristotle, Pliny, and Paracelsus have written largely concerning this fluid, they have confined themselves to the imperfect examination of some of its physical properties, to the mention of a few obvious facts, and to the invention of hypotheses, which, as they do not profess to be founded on experiment, may, in the present state of knowledge, be safely neglected.

It was, indeed, natural, that the great improver of Otto Guericke's original air-pump, fond as he was of chemical pursuits, should exercise his talents in researches on the properties of the atmosphere, more especially as, from the number of substances continually assuming the form of vapour, it was not improbable that common air should prove a very heterogeneous and easily decomposable mixture. The

difficulty, however, of separating, by the only method then known, a portion of air from the rest of the atmosphere, and the necessary uncertainty of the first rude attempts to operate upon an invisible elastic substance, occasioned the progress of discovery in this department of chemical science to be unusually slow. The following facts, however, were ascertained by Boyle, which, when we consider the numerous obstacles from bad and imperfect apparatus that he had to contend with, are highly creditable to his industry and sagacity. He proved, that the presence of air was necessary to combustion and to animal life, by shewing, that in the exhausted receiver flame was almost immediately extinguished, and various small animals, and even fish, while in water, were in a short time killed: that the same phenomena take place, but more gradually, in a confined portion of atmospheric air; and that the death of animals, in this situation, was not owing to the heated exhalations from their bodies, as was then supposed, since the same effects took place when the apparatus was put into a frigorific mixture: he also ascertained, that animals live longer, *ceteris paribus*, in a given bulk of condensed than of rarefied air. On account of the imperfection of his apparatus, he was induced to believe, that no absorption of air took place in respiration; and he appears to have had no suspicion that pure atmospheric air was a compound substance.

Immediately after Boyle, succeeded Mayow, unquestionably the greatest chemical genius of that age, but whose works, by a singular fatality, excited little or no interest among his contemporaries, and were soon totally forgotten. In this state of unmerited neglect they remained for more than a century; and it is only within a very few years, that the public attention has been directed to the writings of a philosopher, who nearly anticipated those discoveries of Priestley, Lavoisier, and Cavendish, upon which are based almost all the modern improvements in chemistry. The first great improvement of Mayow in the analysis of atmospheric air, was the invention of a proper apparatus; for this purpose, rejecting the use of the air-pump, he made choice of glass jars, inverted in water, as the best method of confining the gases upon which he experimented. Setting out from the facts discovered by Boyle, he argues, that since a lighted candle is extinguished much sooner in an exhausted receiver than in the same when filled with air, there must be something contained in the atmosphere necessary to the continuance of flame; and that a candle, in confined air, is not suffocated by its own fuliginous exhalations, but dies away for want of an aerial pabulum. The necessity of air to combustion is also proved, says he, from the impossibility of kindling a combustible body in vacuo by the concentrated solar rays, or by any other method. Having established this first position, he proceeds to infer, that it is not the whole air but only its more active particles, that are capable of supporting flame, because a candle goes out in confined air, while yet the greatest part of the elastic fluid remains unconsumed. Alas, since sulphur, when mixed with nitre becomes capable of inflammation in vacuo, or even under water, it follows that nitre and atmospheric air contain some substance in common, which he calls *fire-air* particles (*particule igneo-aeræ*.) He next determined the analogy between flame and animal life; and shewed, that each depended for their continuance on a supply of fire-air particles: that there was an actual consumption of air in combustion and respiration he proved, by the rise of water in the jars in which a live animal or a lighted candle was inclosed; and that the loss of bulk was owing to the abstraction of fire-air, appeared from the inability of the residue to support animal life. He also inferred, that the fire-air

particles were the heaviest part of atmospheric air, because, if two mice or two candles were confined in a tall cylindrical jar, inverted in water, so as that one should be near the upper part of the vessel, and the other at the bottom, the upper one, whether a candle or animal, would be extinguished some time before the lower one. With regard to the proportion of fire-air in the atmosphere, he only observed, that air rendered unfit for combustion by the breathing of an animal, lost about one fourteenth of its bulk; at the same time remarking, that there was probably only a part of the fire-air consumed: he afterwards, indeed, found, that the solution of iron in aquafortis occasioned a diminution of about 25 per cent. in atmospheric air; but though, in this case, he produced nitrous gas, and thus abstracted the oxygen of the atmosphere, yet, as he himself draws no conclusions from it, we should rather consider this as an accident than a discovery. Mayow never obtained the fire-air of the atmosphere in a separate state, and therefore was unable to confirm his analysis of atmospheric air by the synthetical proof; nevertheless, he was warranted by a very high probability in affirming that the atmosphere consisted of two kinds of air, of which the igneo-aerial was in the proportion of at least one to 13; that it exceeded the other part in its specific gravity, and was absolutely essential to the continuance of flame and animal life. The influence, however, of the prevalent hypothesis was at that time too strong to be shaken by sober experiment; and the labours and very name of Mayow, shortly sunk into oblivion: the atmosphere was still supposed to be an undecomposable element, and its effect on chemical processes was very generally overlooked.

In 1774, exactly a century after the publication of Mayow's work, the important discovery of dephlogisticated air, by Dr. Priestley, took place. This philosopher having inclosed some *mercurial precipitate per se*, in a jar filled with mercury, and inverted over the same, procured from it, by means of heat, a quantity of gas, in which a candle burnt with an enlarged flame, and increased light: the coincidence of this, with the effect produced by dephlogisticated nitrous gas in the same circumstances, as had been already observed by Dr. Priestley, induced him to believe that there was some common principle in nitrous acid and atmospheric air; and this suspicion was still further confirmed by the discovery, that common *red precipitate*, which is prepared by means of nitrous acid, yielded dephlogisticated air in the same manner as the precipitate *per se*. Hence, too, he concluded, that pure atmospheric air was not an element, and that dephlogisticated air was that one of its component parts to which the continuance of flame and animal life was entirely owing. Thus we find, both Mayow and Priestley arriving at the same general conclusions, through the medium of entirely different experiments; the fire-air of the one, and the dephlogisticated air of the other, being only two words for the same substance: the experiments of the latter possess, however, this capital superiority, that they exhibit in a separate uncombined state, that vital part of the atmosphere, the existence of which was only to be inferred from those of the former. There yet remained, however, for the complete proof of the composition of the atmosphere, that a part of it should be actually decomposed, so as to shew its elements separated; and then, by their union, to recombine atmospheric air. This deficiency was supplied by Lavoisier. He confined a few ounces of mercury and a certain portion of atmospheric air in a proper glass apparatus, and exposed the mercury for 12 days to a heat nearly equal to that of ebullition; during this period a part of the mercury was converted into a red oxyd, a certain portion of

the air disappeared, the remainder was incapable of supporting flame, and the weight of the red oxyd exactly corresponded with the loss sustained by the mercury and the air; this red oxyd, being then heated in a small retort, was decomposed into running mercury and a gas which exhibited all the properties of dephlogisticated air; finally, this air, being mingled with the unrespirable residue, recomposed atmospheric air. From these and various other similar experiments, it appeared, that the lower part of the atmosphere consists of 27 parts OXYGEN gas, and 73 of a mephitic air, which, upon a further analysis, yielded about 72 parts of AZOTIC gas, and one of CARBONIC acid. These experiments will be further detailed under the term EUDIOMETRY.

From the slight adherence of these gasses with each other in the air, it is probable that they are not so much in a state of combination as of intimate mixture; and hence there are scarcely any chemical actions produced by the atmosphere, which are not more properly referable to some one or other of its constituent parts.

Atmospherical air, as such, is soluble in water; from which it may be separated by the action of the air-pump, or by long boiling or distillation; hence fish, confined in fresh distilled water, soon die for want of air: if, however, the water has been previously exposed to the atmosphere, a sufficient portion is absorbed to supply the demands of these animals. In like manner water is soluble in air, but the proportion of this must necessarily vary according to the differences in temperature and barometrical pressure. Boyle's works, vol. ii. Mayow, Tractatus, &c. Priestley on Air. Lavoisier's Elements.

AIR, *factitious*. While pneumatic chemistry was in its infancy, all those elastic fluids produced in chemical experiments, were distinguished by this appellation from the

air of the atmosphere; since, however, these factitious airs have acquired peculiar names, the term has fallen into disuse.

- AIR, ACID. } See MURIATIC ACID.
 - MARINE. }
 - AIR, FIXED. } See CARBONIC ACID.
 - FIXABLE. }
 - MEPHITIC. }
 - AIR, VITRIOLIC ACID, See SULPHUREOUS ACID.
 - AIR, FLUORIC ACID. } See FLUORIC ACID.
 - SPARKY ACID. }
 - AIR, DEPHLOGISTICATED MARINE. See OXYMURI-
ATIC ACID.
 - AIR, VEGETABLE ACID. See ACETOUS ACID.
 - AIR, NITROUS. See NITROUS GAS.
 - AIR, DEPHLOGISTICATED NITROUS. See NITROUS
OXYD.
 - AIR, MEPHITIC ATMOSPHERICAL. }
 - PHLOGISTICATED. } See AZOT.
 - NITROGENOUS. }
 - AIR, VITAL. }
 - PURE. } See OXYGEN.
 - FIRE. }
 - DEPHLOGISTICATED. }
 - AIR, INFLAMMABLE. See HYDROGEN.
 - AIR, SULPHURATED INFLAMMABLE. } See HYDROGEN
— HEPATIC. } *sulphurated.*
 - AIR, HEAVY INFLAMMABLE. See HYDROGEN carbonated,
or CARBON, *gaseous oxyd of.*
 - AIR, ALKALINE. See AMMONIA.
- For an account of Dr. Priestley's numerous experiments and observations on these several species of air, the reader is referred to the excellent work already cited.

Air-Gun

Air-gun, or *Wind-gun*, a machine which serves to explode bullets, and other shot, with great violence, by the expansive force of the air. This sort of implement, charged with air, has an effect scarcely inferior to that of a common fire-arm charged with gun-powder; but it discharges itself with a much less report; and it is this which probably gave occasion to the fable of white gun-powder. The first account of an air-gun, that has been noticed, is found in the *Elemens d'Artillerie* of David Rivaut, who was preceptor to Louis XIII. of France. He ascribes the invention to one Marin, a burgher of Lisieux, who presented one to Henry IV.

The common air-gun (*Pneumatics*, Plate iii. *fig.* 14.) is made of brass, and has two barrels: the inside barrel K A of a small bore, from which the bullets are shot, and a

larger barrel E C D R on the outside of it. In the stock of the gun there is a syringe, S M N P, whose rod M draws out to take in air, and piston S N drives the air before it through the valve E P into the cavity between the two barrels. The ball K is put down into its place in the small barrel with the rammer, as in another gun. There is another valve at S L, which, being opened by the trigger O, permits the air to come behind the bullet, so as to drive it out with great force. If this valve be opened and shut suddenly, one charge of condensed air may make several discharges of bullets; because only part of the injected air will go out at a time; and a new bullet may be put into the place K; but if the whole air be discharged on a single bullet, the ball

ball will be expelled more forcibly. This discharge is effected by means of a lock *l* (*fig.* 15.) placed here as in other guns; for the trigger being pulled, the cock *k* will go down, and drive a lever *o*, that will open the valve, and let in the air upon the bullet *K*.

An air-gun of the most modern and approved construction is represented in *fig.* 16. *A* is the iron gun-barrel, with the lock, stock, ram-rod, &c. of about the size and weight of a common fowling-piece. Under the lock at *b* is a round steel-tube, with a small moveable pin in the inside, which is pushed out by the spring of the lock, when the trigger *a* is pulled. To this tube, *b*, is screwed a hollow copper-ball, *c*, containing a spring-valve at its aperture; and perfectly air-tight. Each gun has usually two of these balls, which are fully charged with condensed air by means of the condensing syringe *B*, *fig.* 17. Having rammed down the leaden bullet into the barrel, and screwed the copper ball home to the lock at *b*, let the trigger, *a*, be pulled, and the pin at *b* will be forcibly and instantly driven out against the valve in the ball, and will thus liberate a portion of the condensed air; which, rushing up through an aperture in the lock into the barrel immediately before the ball, will impel it to the distance of, at least, 60 or 70 yards. By recocking the piece, another discharge may be immediately made, and thus repeated 15 or 16 times, with a very small hissing noise, which at a distance is not audible. The condensed air is forced into the ball by the following apparatus. The ball, *c*, is screwed to the brass syringe *B* (*fig.* 17.) quite close. In this syringe is adapted a moveable piston and iron rod, *a*, at the end of which is a strong ring, into which is placed a stout iron rod, *k* *k*: upon this rod the feet are firmly placed, and the hands are applied to the wooden handles, *i* *i*, fixed to the syringe. By steadily moving the barrel *B*, up and down on the rod *a*, the ball, *c*, will become charged with condensed air; and it is easily known when it is filled to the utmost by the irresistible action which the air makes against the piston, when you are working the syringe. At the end of the rod *k*, is usually an eight-square hole, which serves as a key to make the ball fast on the screw, *b*, of the gun, and on the syringe. The piston-rod works air-tight by a collar of leathers on it, in the barrel, *B*; and therefore, when the barrel is pulled up, fresh air will rush in at the hole *b*; when the barrel is pushed down, the air in it can only pass into the ball at top; the barrel being drawn upwards, the operation is repeated, until the condensation is so strong as to resist the action of the piston.

Dr. Macbride (*Exper. Eff.* p. 81.) mentions an improvement of the air-gun by Dr. Ellis, in which the chamber for containing the condensed air is not in the stock, which makes the machine heavy and unwieldy, but has five or six hollow spheres belonging to it, of about three inches diameter, fitted to screw on the lock of the gun. These spheres are contrived with valves for confining the air, which is forced into their cavities, so that a servant can carry them ready-charged with condensed air; and thus the gun of this construction is rendered as light and portable as one of the smallest fowling-pieces.

The magazine air-gun is an improvement of the common air-gun, invented by an ingenious artist called L. Colbe. By his contrivance ten bullets are so lodged in a cavity, near the place of discharge, that they may be drawn into the shooting barrel, and successively shot so quickly, as to be nearly of the same use with so many different guns; the only motion required, when the air has been previously injected, being that of shutting and opening the hammer, and cocking and pulling the trigger. In *fig.* 18, is exhibited a section of the gun, as large in every part as the gun

itself; and so much of its length is shewn as is necessary to give a complete idea of the whole. *A E E* is part of the stock; *G* is the end of the injection syringe, with its valve, *H*, opening into the cavity, *F F F F*, between the barrels. *K K* is the small or shooting barrel, which receives the bullets, one at a time, from the magazine, *E D*, which is a serpentine cavity, wherein the bullets, *b, b*, &c. are lodged, and closed at the end *D*. The circular part, *S I & M i*, is the key of a cock, having a cylindrical hole, *I K*, through it, equal to the bore of the small barrel, and forming a part of it in the present situation. When the lock is taken off, the several parts, *Q, R, T, S, W*, &c. come into view, by means of which the discharge is made, by pushing up the pin, *P p*, which raises and opens a valve, *V*, to let in the air against the bullet, *I*, from the cavity, *F F F*; which valve is immediately shut down again by means of a long spring of brass, *N N*. This valve, *V*, being a conical piece of brass, ground very true in the part which receives it, will of itself be sufficient to confine the air. To make a discharge, pull the trigger, *Z Z*, which throws up the sear, *y x*, and disengages it from the notch, *x*; upon which the strong spring, *W W*, moves the tumbler, *T*, to which the cock is fixed. The end, *u*, of this tumbler bears down the end *v*, of the tumbling lever, *R*, which, by its other end, *m*, raises the flat end, *l*, of the horizontal lever, *Q*, by which means the pin, *P p*, is pushed up, and opening the valve, *V*, discharges the bullet; all which is evident from a bare view of the figure.

To bring another bullet instantly to succeed *I*, there is a part *H*, called the hammer, represented in *fig.* 19. and *fig.* 20. which by a square hole goes upon the square end of the key of the cock, and turns it about so as to place the cylindric bore of the key *I k*, in any situation required.

Thus, when the bullet is in the gun, the bore of the key coincides with that of the barrel *K K*; but when it is discharged, the hammer *H* is instantly brought down to shut the pan of the gun; by which motion the bore of the key is turned into the situation *ik*, so as to coincide with the orifice of the magazine; and upon lifting the gun upright, the ball next the key tumbles into its cavity, and falling behind two small springs, *s s*, *fig.* 18. is by them detained. Then opening the hammer again, the ball is brought into its proper place, near the discharging valve, and the bore of the key again coincides with that of the shooting barrel. It appears how expeditious a method this is of charging and discharging a gun; and if the force of condensed air was as great as that of gunpowder, such an air-gun would actually answer the end of many guns, and prove the best defence against highwaymen or robbers; because, when there is reason to suspect them, they might then make five or six discharges before the robber can come within pistol-shot.

From the experiments of Mr. Robins, in his *New Principles of Gunnery*, (See *Mathem. Tracts of Robins*, by Wilson, vol. i. p. 73.) it appears, that the force of gunpowder, at the moment of its explosion, is 1000 times greater than that of the elasticity of common air; and, therefore, that the latter may produce the same effect with the former, its condensation must be 1000 times greater than that of its natural state. But as the velocities with which equal balls are impelled are directly proportional to the square roots of the forces, the velocity with which an air-gun, containing air condensed only ten times, will project a ball, will be $\frac{1}{10}$ th of that arising from gunpowder; and if the air were condensed 20 times, it would communicate a velocity of $\frac{1}{4}$ th of that of gunpowder. In the air-gun, however, the reservoir of condensed air is commonly very large, in proportion to the tube which

contains the ball, and its density will be very little altered by expanding through that narrow tube; consequently the ball will be urged by nearly the same uniform force with that of the first instant: whereas the elastic fluid of inflamed gun-powder, bears a small proportion to the barrel of the gun, and by dilating from the small portion of it near the but-end into a comparatively large space, its elastic force will be proportionally weakened, and its action on the ball in the barrel will become gradually less and less. Hence it appears, that the air-gun will project its ball with a much greater proportional degree of velocity than that which is above stated; inasmuch that air condensed ten times will produce a velocity not much inferior to that arising from the gun-powder.

However, in this kind of gun, and in all cases which require a very considerable condensation of air, it will be requisite to have the syringe of a small bore, viz. not exceeding half an inch in diameter; because the pressure against every square inch is about 15 pounds, and against every circular inch about 12 pounds. If, therefore, the syringe be one inch in diameter, when one atmosphere is injected, there will be a resistance of 12 pounds against the piston; when two, of 24 pounds; and when ten are injected, there will be a force of 120 pounds to overcome; whereas ten atmospheres act against the circular half inch piston, whose area is but one-fourth part so big, with a force but one-fourth as great, viz. 30 pounds; or 40 atmospheres may be injected with such a syringe as well as ten with the other. Defaguliers's Exp. Phil. vol. ii. p. 398, &c. Martin's Phil. Brit. vol. ii. p. 189, &c. Adams's Lect. on Nat. and Exp. Phil. by Jones, vol. i. p. 133.

Air-jacket, a jacket of leather, furnished with bags or bladders of the same material, inflated with air, and serving to buoy up the person who wears it, and to prevent his sinking in water, without any effort of swimming. These bags communicate with each other, and are filled with air by means of a leathern pipe, having at the end of it a stop-cock, accurately ground, so as to admit the injected air, and, when closed, to prevent its escape. The jacket must be well moistened with water before the bags are filled: otherwise the air will escape through the pores of the leather.

Air-lamp, a pneumatic machine, formed by the combination of inflammable air and electricity, which, by turning a stop-cock, produces a flame that may be restrained or continued at pleasure. The contrivance of machines of this sort was suggested by the experiments of Mr. Volta, Dr. Ingenhouz, &c. The air-lamp is now constructed in the following manner. A, (*Plate iii. Pneumatics, fig. 21.*) is a glass jar for containing the inflammable air; B, an open glass urn, that contains water, by the pressure of which the air is forced out of the jar A, through the brass-pipe *a*; C, is the stop-cock, so perforated, that the water may descend from B into A, and the air pass out through the pipe *a*. By turning the bar of the stop-cock to an horizontal position, the communication between the two vessels is closed, and the passage of the air obstructed; and by turning it into a vertical position, the communication is opened. The lower jar, A, is supplied with inflammable air by means of the bladder, (*fig. 22*); and two bladders of this kind accompany each lamp. It is used in the following manner: Take off the cover D, from the lamp, and turn the stop-cock upwards; then pour as much clear water into it as will fill the vessel, A, up to the pipe *a*; unscrew this pipe, and in its stead screw the small brass piece (*fig. 23.*) and to this screw one of the stop-cocks and bladder, (*fig. 22.*) With the bladder under one arm, one hand

to the cock at C, and the other to that of the bladder, open the apertures and press the bladder at the same time; and thus the air will be forced upon the water in A, and driven up the glass pipe through the tube into B, with a bubbling noise. When the vessel, A, is thus charged with air, the stop-cocks are to be turned, so as to cut off the communication with the external air. Care must be taken that the common atmospheric air does not mix with the inflammable; for if a mixture of these airs were fired, the explosion would be great and dangerous.

The apparatus for lighting this lamp is of the electrical kind; and it is as follows. The mahogany basis, E F, is a sort of box, about 12 inches square, and 5 inches deep; and in this is placed an electrophorus, consisting of a resinous cake *c*, and metallic plate *d*, which by a hinge at its back, admits of being pulled upwards and let down by the silken string *b*, connected both with it and with the stop-cock C. When this cake is once excited, its electrical effect upon the metal plate will be continued for a long time. A metallic chain, G, communicates with a wire and ball *e*, passing through a glass tube below, in the box over the plate, and above with a fine wire passing through a glass tube. This upper wire is bent to about $\frac{1}{4}$ th of an inch distance from the flame-pipe. It is evident that when the electrophorus in the box is previously excited, and the stop-cock, C, turned, the silken string, *b*, will raise the metallic plate; and this will give an electric spark to the ball and wire above, which will convey it instantly to the flame-pipe, and inflame the air issuing out of the pipe, in consequence of the pressure of the water in its descent into the vessel A. The cock, C, being turned back, the flame ceases; and turned again, appears; and will serve to light a candle, match, &c. whenever it may be thought proper. The number of times in which light may be produced will be very great, and will depend on the quantity of the inflammable air in the vessel A. If the cock is not turned back, the flame will continue till the whole of the inflammable air is consumed. The light thus produced will be sufficient for reading a large print in the night, or seeing the hour by a watch. When the electrophorus is to be excited, the silken string, *b*, is unhooked from the plate, and the apparatus taken out of the box; and the metallic plate is lifted up, whilst, with a silken or dry cat-skin rubber, you briskly rub the surface of the resinous cake. About 20 revolutions in rubbing will be sufficient, so that the plate will give a spark to the knuckle about the distance of an inch; and by the strength of the spark the degree of excitation is to be estimated. The silken string and small glass tubes, through which the wire, G, passes, should always be very dry, that the passage of the electrical spark may be quite perfect. The whole length of this apparatus is about 22 inches; but it may be made of any dimensions. Dr. Ingenhouz used a small apparatus, constructed upon a similar principle, in obtaining light for domestic purposes, both when at home and on his travels. Adams's Lectures by Jones, vol. ii. p. 99, &c.

Air-pipes, a contrivance invented by Mr. Sutton, a brewer of London, for clearing the holds of ships and other close places of their foul air. The principle upon which this contrivance is founded is well known. It is no other than the rarefying power of heat, which, by causing a diminution of the density of the air in one place, allows that which is in contact with it to rush in, and to be succeeded by a constant supply from remoter parts, till the air becomes every where equally elastic. If a tube, then, be laid in the well, hold, or any other part of a ship, and the upper part of this tube be sufficiently

heated to rarefy the impending column of air, the equilibrium will be maintained by the putrid air from the bottom of the tube, which being thus drawn out, will be succeeded by a supply of fresh air from the other parts of the ship; and by continuing the operation, the air will be changed in all parts of the ship. Upon this principle, Mr. Sutton proposed to purify the bad air of a ship, by means of the fire used for the coppers, or boiling places, with which every ship is provided. Under every such copper or boiler there are two holes separated by a grate, one for the fire and the other for the ashes; and there is also a flue, communicating with the fire-place, for the discharge of the smoke. The fire, after it is lighted, is preserved by the constant draught of air through these two holes and the flue; and if the two holes are closed, the fire is extinguished. But when these are closed, if another hole communicating with any other airy place, and also with the fire, be opened, the fire will of course continue to burn. In order to clear the holds of the ships of the bad air, Mr. Sutton proposed to close the two holes above mentioned, viz. the fire-place and ash-place, with substantial iron doors, and to lay a copper or leaden pipe of sufficient size from the hold into the ash-place, and thus to supply a draught of air for feeding the fire; a constant discharge of air from the hold will be thus obtained, and fresh air will be supplied down the hatches, and by such other communications as are open into the hold. If other pipes are connected with this principal pipe, communicating either with the wells or lower decks, the air that serves to feed the fire will be drawn from such places.

In large ships, there is not only a copper, but a fire-grate, like those used in kitchens; behind this grate an iron tube might be fixed, and inserted quite through the brick-work and through the deck, so that one end of it might stand about a foot, or somewhat more, in the chimney above the brick-work, and the other made to enter into the hold or any other part of the ship. When the upper end of this tube is heated, the draught of air will be supplied from below, as in the other case. Mr. Sutton's practicable and useful contrivance was much opposed at its first proposal; and though his pipes were recommended by Dr. Mead and Mr. W. Watton, after several trials of their effect, they were very slowly introduced, and in process of time very much neglected. Mr. Sutton, after considerable delay, and with no small difficulty, obtained a patent for his invention.

Mr. Watton recommends the use of these pipes for the circulation of fresh air in houses, prisons, hospitals, wells, &c. And they have undoubtedly this obvious advantage, that by causing the putrid and noxious air to pass into the fire, they not only dissipate but destroy it. Phil. Trans. abr. vol. viii. p. 628. 630. Mead's Works, p. 397—437.

For other inventions adapted to the same purpose, see *AIR-TURN, BELLOWS, SHIP'S-LUNGS, VENTILATOR, BLOWING-WHEEL, and WIND-SAILS.*

AIR-PUMP, a machine, by means of which the air may be exhausted out of proper vessels.

The use and effect of the air-pump is to make what we popularly call a *vacuum*; but this, in reality, is only a degree of rarefaction sufficient to suspend the ordinary effects of the atmosphere.

By this machine, therefore, we learn in some measure, what our earth would be without an atmosphere; and how much all vital, generative, nutritive, and alterative powers, depend upon it.

The principle on which the air-pump is constructed, is the elasticity of the air; as that on which the common, or water-pump is founded, is the gravity of the same air.

The structure of the air-pump is, in itself, more simple even than that of the water-pump.—The latter supposes two principles, gravity and elasticity likewise: so that the water-pump must first be an air-pump, i. e. it must rarefy the air before it can raise the water.—In effect, water being a dormant unelastic fluid, needs some external agent to make it ascend; whereas air ascends in virtue of its own elastic activity: its natural tendency is to separate and leave a vacuum; and all that remains for art is to prevent the ambient air from supplying the place of that which thus spontaneously escapes. To make water ascend, the force wherewith it is pressed downwards is either to be diminished or increased in one part more than another; like a balance in *equilibrio*, one of whose scales may be made to rise, either by diminishing its own weight, or increasing that of the other; the water, therefore, recedes from the common centre of gravity by the very power with which it tends towards it indirectly or secondarily applied; because, two similar centripetal forces being made to act contrary to each other, what in the one over-balances the other must have the effect of a centrifugal force.—Whereas, the principle whereby air is rarefied or diminished, does not respect the centre of the earth, but the centres of its own particles; being no other than a certain implanted power, whereby they immediately tend to recede from each other.

The invention of this noble instrument, to which the present age is indebted for so many fine discoveries, is ascribed to Otto de Guericke, the celebrated consul of Magdeburg, who exhibited his first public experiments with it, before the emperor and the states of Germany, at the breaking up of the imperial diet at Ratisbon, in the year 1654: but his description of the instrument, and of the experiments performed with it, is contained in his "*Experimenta nova Magdeburgica de Vacuo Spatio*," and was not published before the year 1672, at Amsterdam.

Dr. Hooke and M. Duhamel, indeed, ascribe the invention of it to Mr. Boyle; but that ingenious author frankly confesses de Guericke to have been beforehand with him. In a letter which he wrote to his nephew, Lord Dungarvan, at Paris, about two years after Schottus's book was published, he introduces the acknowledgment of his obligation, for the discovery of this useful machine, to what he had heard of it, though he had not then perused it, by that well-applied passage of Pliny, *benignum est et planum ingenii pudoris fateri per quos profeceris*. Some attempts, he assures us, he had made upon the same foundation, before he knew any thing of what had been done abroad: but the information he afterwards received from Schottus's *Mechanica Hydraulico Pneumatica*, published in 1657, wherein was an account of de Guericke's experiments, first enabled him to bring his design to any thing of maturity. From hence, with the assistance of Dr. Hooke, after two or three unsuccessful trials, arose a new air-pump more easy and manageable than the German one; and hence, or rather from the great variety of experiments that illustrious author applied it to, the engine came to be denominated *machina Boyleana*, and the vacuum produced by it, *vacuum Boyleanum*.

AIR-PUMP, structure and use of the. The basis or essential part in the air-pump, is a metalline tube, answering to the barrel of a common pump, or syringe; having a valve at the bottom, opening upwards; and a moveable piston or embolus, answering to the sucker of a pump, furnished likewise with a valve opening upwards. The whole must be duly fitted to a vessel as a recipient or receiver.

The rest being only circumstances chiefly respecting conveniency, have been diversified and improved from time

to time, according to the several views and address of the makers.

In our further account of the air-pump, we shall trace the various alterations it has undergone from the rude and inconvenient construction of Otto de Guericke to its present improved state. Guericke's machine is exhibited in *Plate iv. Pneumatics, fig. 24.* It consists of an iron three-legged frame, *a b c d f*, supporting a round iron plate, *b c*, in the middle of which is inserted a brass syringe, *g h*. The upper part of this syringe is furnished with a rim of lead, *y*, (*fig. A.*); and it is fastened below by means of an iron ring, *k k*, and three iron arms, *o o o*, to the legs of the frame. Within the rim *y*, there is a brass plate *m n*, (*fig. B.*) encompassed by a ring of leather, and fixed by three screws which terminate upwards in a small tube *n*, into which the pipe connected with the vessel to be exhausted is inserted, as occasion requires, and to which, on the lower side, is adapted a valve of leather, through which the air passes into the syringe. In this plate there is also another small valve at *z*, opening upwards, through which it escapes. This plate is covered by a copper vessel, *x x*, intended for containing water. The piston of the syringe *s h*, (*fig. 24*, and *fig. C.*) is connected by a joint at *t*, with the iron rod *t u*, which is fastened to the handle, *w u u*; and this moves round the pin at *u*, by which it is connected with one of the legs of the frame. In order to prevent air from entering into the syringe, a copper vessel of water is suspended by hooks to the arms, *o, o, o*, so that the lower part of the syringe at *k k*, and the piston, may be always covered with water, when the machine is at work. The receiver, *L*, is a glass sphere, adapted to a brass cap, *P P*, which has a pipe with a stop-cock, *q r*; and this pipe is fitted to the tube, *n*, above mentioned. From this brief description of the machine, its operation will be easily understood. When the piston, *s h*, is depressed, the air will be expanded in the syringe, *g h*, and that of the receiver will descend into it through the valve in the lower surface of the plate, *m n*; but when the piston is elevated, and the air is compressed, this valve shutting upwards will close the passage to the receiver, and make its escape through the valve *z*, which opens upwards. In order to render the exhaustion more complete, a small exhausting syringe is adapted to the plate, which is represented at *m*. See Guericke's *Exper. Nov. Magdeb. Amd. 1672. lib. iii. c. iv. and v. p. 77.*

This machine, though it might be deemed an excellent contrivance at the time of its invention, when the doctrine of the elasticity and expansion of the air was new, had many defects which it is hardly necessary now to mention. The force necessary for working it was very great, and the progress of its operation very slow. Besides, it was to be wrought under water, and it allowed of little change of subjects for experiments. Mr. Boyle, whose ideas of this machine, first suggested to him by Schottus's report of Guericke's construction, were executed by Dr. Hooke, whom he then employed as his operator, removed some of these inconveniences and diminished others.

The form of Mr. Boyle's air-pump appears in *Plate iv. Pneumatics, fig. 25.* It consisted of a spherical receiver, *A*, with a round hole at the top, whose diameter, *B C*, was about four inches; this was covered with a plate, having a brass rim, *D E*, which was firmly cemented to the ring of glass that surrounded the hole; and to the tapering orifice of the brass rim was adapted a brass stopple, *F G*, ground so exactly as to exclude as much as possible the admission of air. In the centre of the cover was a hole, *H I*, of about half an inch in diameter, provided with a socket, to which

the brass stopple, *K*, was so fitted as to prevent the entrance of air; and the lower part of this stopple was perforated with a hole, through which passed the string, *8, 9, 10*, for the convenience of moving to and fro the subjects of experiments. To the neck of the receiver a stop-cock, *N*, was fastened; and to the shank of the cock, *X*, a tin-plate, *M T U W*, was so cemented as to preclude the admission of air. The lower part of this machine consisted of a wooden frame with three legs, *1 1 1*, and a transverse board, *2 2 2*, on which the pump rested. The cylinder of this pump was cast brass; and it was fitted with a sucker, *4 4, 5 5*; of which one part, *4 4*, was covered with shoe-leather, so as exactly to fill the cavity of the cylinder; and to this was fastened the other part, which was a thick and narrow plate of iron, *5 5*, somewhat longer than the cylinder, indented on one edge with narrow teeth, so as to admit the corresponding teeth of a small iron nut, fastened by two flaps to the under side of the transverse board *2, 2, 2*, on which the cylinder rests; and this is turned to and fro by the handle, *7*. The last part of this cylinder is the valve, *R*, consisting of a hole bored through at the top of the cylinder, somewhat tapering towards the cavity; into which hole is ground a tapering peg of brass, to be thrust in and taken out at pleasure. In order to prevent more effectually the admission of air, and to prepare the sucker of the pump for motion, a quantity of salad oil was poured in at the top of the receiver and also into the cylinder. The operator, having fixed the lower shank, *O*, of the stop-cock into the upper orifice of the cylinder, turns the handle, and thus forces the sucker to the top of it, so that no air may be left in its upper part. Then shutting the valve with the plug, and turning the handle the other way, he draws down the sucker to the bottom of the cylinder, and thus its cavity, into which no air is admitted, will be in an exhausted state. By turning the stop-cock, and opening a passage between the cylinder and the receiver, the air contained in the one will descend into the other; and this air being prevented from returning, by turning back the key of the stop-cock, will be made to open the valve and to escape into the external air by forcing the sucker to the top of the cylinder; by alternately moving the sucker upward and downward, turning the key and stopping the valve, as occasion requires, the exhaustion may be continued. See Boyle's Works, by Birch, vol. i. p. 7—10.

Mr. Boyle has described a second air-pump in the first continuation of his Physico-mechanical experiments. See his works, vol. iii. p. 180. This, like the former, had only one barrel, by which the receiver was exhausted; but it was so contrived as to be every where surrounded with water, that the ingress of air might be more effectually prevented. Besides, the receivers, which were of several forms and sizes, were fastened to an iron plate by means of a soft cement, so that they could be removed and changed at pleasure. The interposition of a moistened leather for fixing them, does not seem at this time to have occurred to him.

Notwithstanding all the precautions of Mr. Boyle, and his contrivances for excluding air by oil and leather, he found that the working of his pump by a single barrel was laborious, on account of the pressure of the atmosphere, a great part of which was to be removed at every elevation of the piston, when the exhaustion was nearly completed; and he himself candidly acknowledges, that it was rarely and with great difficulty, that he was able to produce any great degree of rarefaction. This useful machine was gradually improved by Papin, Merfenne, Mariotte, and others; but the introduction of a second barrel and piston was the

principal improvement which it received about this period. To whom this was owing, it is not easy to decide: some ascribe it to Dr. Hooke, others to Papin, and others again to Hauksbee. An engine of this kind, with a double tube, is described by Mr. Boyle, in the second continuation of *Physico-mechanical Experiments*, (works, vol. iv. p. 510.); but the manner of working it, by means of a pulley and of iron stirrups or treddles, upon which the operator stood, must have been extremely inconvenient. However, by the use of a second barrel and piston, contrived to rise and fall alternately with the other, and by the introduction of valves, which in this third air-pump of Mr. Boyle supplied the place of the plug and stop-cock which he had before used, as well as by the subsequent improvements of Hauksbee, the pressure of the atmosphere on the descending piston always nearly balanced that of the ascending one; so that the winch which worked them up and down was easily moved by a gentle force with one hand; and the exhaustion was also made in much less time. See Hauksbee's *Physico-Mechanical Experiments*, p. i., &c. Mr. Vream, a pneumatic operator, employed by Desaguliers, made an improvement in Hauksbee's air-pump, by reducing the alternate motion of the hand and winch to a circular one. In his method the winch is turned quite round, and yet the pistons are alternately raised and depressed; by which the trouble of shifting the hand backwards and forwards, as well as the loss of time, and the shaking of the pump, are prevented. See Desaguliers's *Course of Exp. Philos.* vol. ii. p. 378. For a brief account of the progressive improvements of the air-pump, see Cotes's *Hydrostatical and Pneumatical Lectures*, lect. xii. p. 156, &c.

The structure of the air-pump, thus improved, is represented in *Plate v. Pneumatics*, fig. 33. It consists of two brass barrels or cylinders, *a a*, *a a*, which communicate with each other by the cistern *d d*, and with the receiver *o o o o*, which is ground level at the bottom, and set over a hole in the plate, by means of the bent pipe, *b b*. In these barrels the pistons, which are fastened so tight that no air can get between them and the barrels, are worked by a toothed wheel, turned by the handle, *b b*; and thus the racks, *c c*, with their pistons, are worked alternately up and down. The gage tube, *l l*, is immersed in a basin of quicksilver *m*, at the bottom, and communicates with the receiver at the top; from which it may be occasionally disengaged by turning a cock; and *n* is another cock, by turning of which the air is again let into the exhausted receiver, passing into it with a hissing noise. The action of the toothed wheel and pistons is represented in fig. 34.

As the handle is turned backwards, it raises the piston *d e*, in the barrel B K, by means of the wheel E, and rack D *d*; and as no air can get between the piston and barrel, all the air above *d* is lifted up towards B, and a vacuum is made in the barrel from *e* to *b*; upon which part of the air in the receiver by its spring rushes through the hole in the brass plate of the pump along the pipe G G, communicating with both barrels by the hollow trunk I H K, and pushing up the valve *b*, enters into the vacant part *b e*, of the barrel B K. Then, as the handle, F, is turned forward, the piston, *d e*, will be depressed in the barrel; and the air which had got into the barrel, finding no way of escape through the closed valve *b*, will ascend through a hole in the piston, and make its way into the external air through a valve at *d*; and it will be prevented by that valve from returning into the barrel, when the piston is again raised. At the next elevation of the piston, a vacuum is again made in the same manner as before, between *b* and *e*; upon which

more of the air that was left in the receiver will get out by its spring, and flow into the barrel, B K, through the valve *b*. The other piston and barrel act in the same manner; and as the handle, F, is turned backwards and forwards, it alternately raises and depresses the pistons in their barrels; one being raised whilst the other is depressed. By thus repeating the operation again and again, the air in the receiver is at length rarefied to such a degree, that its density does not exceed the thin air remaining in the barrel when the piston is raised: which done, the effect of the air-pump is at an end; the valve cannot now be opened, or if it could, no air would pass it; there being a just equilibrium between the air on each side.

To judge of the degree of exhaustion, there is added the gage-tube, *l l*, open at both ends, and about 34 inches long (fig. 33.), affixed to a wooden ruler, which is divided into inches and parts of an inch, from the bottom where it is even with the quicksilver in the basin, *m*, and continued to the top, a little below the plate of the air pump, to 30 or 31 inches. Hence the air in the tube rarefying as fast as that in the receiver, in proportion as the exhaustion advances, the mercury will be raised by the pressure of the column of external air, prevailing over that of the column of air included; till the column of air, and mercury together, become a balance to that of the external air. When the mercury is thus risen to the same height as it stands in the barometer, which is indicated by the scale of inches added to the gage, the instrument is a just Torricellian tube; and the vacuum may be concluded to be as perfect as that in the upper end of the barometer. When the cock, *n*, is turned, so as to make a communication with the external air; this rushes in and the mercury in the gage immediately subsides into the basin. See GAGE.

In estimating the gradual ascent of the quicksilver in the gage, it is evident that, as we continue to pump, the mercury continues to ascend; and that it approaches always more and more to the standard altitude, or about 29½ inches, more or less according to the variety of seasons. And it is easy to prove, that the defect of the height of the quicksilver in the gage from the standard altitude is always proportionable to the quantity of air which remains in the receiver; that the altitude itself of the quicksilver in the gage is proportionable to the quantity of air which has been exhausted from the receiver; and that the ascent of the quicksilver, upon every turn of the pump, is proportionable to the quantity evacuated by each turn. Let it be considered, that the whole pressure of the atmosphere upon the cistern of the gage is equal to, and may be balanced by, a column of quicksilver of the standard altitude; consequently, when the quicksilver in the gage has not yet arrived to the standard altitude, the defect must be supplied by some other equal force, and that force is the elastic power of the air remaining in the receiver; which communicating with the upper part of the gage, hinders the quicksilver from ascending, as it would otherwise do, to the standard altitude. The elasticity of the air in the receiver is then equivalent to the weight of the deficient quicksilver; but the weight of this is proportionable to the space it should possess, or to the defect of the height of the quicksilver in the gage from the standard height; therefore the elasticity of the remaining air is also proportionable to the same defect. But the density of any portion of air is proportionable to its elasticity, and the quantity in this case is proportionable to the density; and therefore the quantity of air remaining in the receiver is proportionable to the defect of the quicksilver in the gage from its standard altitude.

Hence it follows, that the quantity of air which was at first in the receiver before you began to pump, is proportionable to the whole standard altitude; and consequently the difference of this air, which was at first in the receiver, and that which remains after any certain number of turns, that is, the quantity of air exhausted, is proportionable to the difference of the standard altitude and the before-mentioned defect, that is, to the altitude of the quicksilver in the gage after that number of turns. Hence again it appears, that the quantity of air exhausted at every turn of the pump is proportionable to the ascent of the quicksilver upon each turn. See Cotes's *Hydrost. and Pneum. Lectures*, lect. 13. See GAGE.

There are several inconveniencies attending air-pumps of the common form, though much improved from what they used to be formerly, and many attempts have been made to remedy them. It is a well-known fact, that pumps merely serve to rarefy the air to a considerable degree, and that none of them can produce a complete exhaustion; as the mercury in the gage is not raised by any of them to the height which it occupies in the Torricellian tube, when well purged of air. Few pumps will bring it within $\frac{1}{16}$ th of an inch. Hawksbee's, fitted up according to his own instructions, will seldom bring it within $\frac{1}{4}$ th; pumps with cocks of the best construction, and in the most favourable circumstances, will bring it within $\frac{1}{4}$ th; but none with valves fitted up with wet leather, or to any part of which water or any volatile fluids have access, will bring it nearer than $\frac{1}{4}$ th. Before we proceed to give an abridged account of the improvements that have been made in air-pumps, we observe, that the air-pumps most commonly used are made either with brass stop-cocks, or with valves of oil-skin or of leather, for preventing the return of the air into the receiver, out of which it had been exhausted. Pumps with stop-cocks, when well made and newly put together, are generally found to rarefy the air to a greater degree than those which are made with valves; but after having been used for some time, they become less accurate than those with valves. But the valves are also imperfect; as the external air, pressing upon that in the piston, prevents its rising, when the elastic force of the air in the receiver, under exhaustion, is much diminished. Attempts have been made, particularly by the abbé Nollet and Mr. Gravesande, to perfect the construction of cocks. In Gravesande's double-barrelled pump, the cocks at the bottom of the pistons are turned by an apparatus that is moved by the handle of the pump: the piston has no valve, and the rod is connected with it by a stirrup, as in a common pump. This rod has a cylindric part, which passes through the stirrup, and moves stiffly in it through the space of about half an inch, between a shoulder above and a nut below. The stirrup supports a round plate, which has a short square tube, that fits tight into the hole of a piece of cork, and which has also a square shank, that goes into the square tube. Between the plate and the cork is put a piece of thin leather, soaked in oil, and another is placed between the cork and the plate which forms the sole of the stirrup. When the winch is turned to raise the piston from the bottom of the barrel, the friction of the piston against the barrel keeps it in its place, and the rod is drawn up through the stirrup. The wheel has thus liberty to turn about an inch; and this is sufficient to turn the cock, so as to cut off the communication with the external air, and to open that with the receiver. When this is done, the continued motion serves to raise up the piston to the top of the barrel. When the winch is turned in the opposite direction, the piston remains fixed till the cock is

turned, so as to shut the communication with the receiver; and open that with the external air. The cock has one perforation diametrically through it, and another in a perpendicular direction to this; and after reaching the centre, it passes along the axis of the cock, and communicates with the open air. By this communication, when it is opened, the air rushes in, and balances the pressure on the upper side of the piston in this barrel, so that the pressure on the other must be counteracted by the person who works the pump. In order to obviate this inconvenience, Gravesande put a valve on the orifice of the cock, by tying over it a slip of wet bladder or oiled leather; and by means of this the piston is pressed down, as long as the air in the barrel is rarer than the outward air, just as if the valve was in the piston itself. Gravesande, and also Muschenbroek, extol the operation of this pump, as exceeding that of pumps with valves. But it is evident that no precise estimate of its performance can be obtained, whilst the pistons, valves, and leathers of the pump are prepared by steeping them in oil, and afterwards in a mixture of water and spirits of wine. With this preparation the gage could not be brought within $\frac{1}{4}$ th of an inch of the barometer. Besides, a considerable space is left between the piston and cock, from which the air is never expelled; and if this be made very small, the pump must be worked very slowly; otherwise the air will not have time to diffuse itself from the receiver into the barrel, especially when the expelling force or the elasticity of the air, towards the close of the operation, is very small. The rarefaction will likewise be retarded by the valve, which will not open till the air below the piston is considerably denser than the external air. The cocks in pumps of this kind are subject to become loose by use, and to admit air: an inconvenience which might, indeed, be prevented by placing the barrels in a dish filled with oil. For a figure and description of Gravesande's pump, see Gravesande's *Mathem. Elem. of Natural Philosophy*, by Desaguliers, vol. ii. p. 14. &c. These pumps, if they were ever used in England, have been long superseded by the cheaper and more simple contrivance of valves, formed by tying a strip of bladder over a small hole, through which the air is allowed to pass in one direction only.

In the year 1750, the ingenious Mr. Smeaton directed his attention to the improvement of valve pumps. In considering the structure of these pumps, he observed, that the principal causes of their imperfection are, partly, the difficulty of opening the valves at the bottom of the barrels, and, partly, the piston's not fitting exactly, when put down to the bottom, which leaves a lodgment of air that is of bad effect. The first of these imperfections is owing to the smallness of the common valves, which are made of a piece of thin bladder stretched over a hole generally much less than $\frac{1}{16}$ th of an inch in diameter, and to the adhesion of the bladder to the plate upon which it is spread, by reason of the oil or water with which it is moistened: as the rarefaction of the air in the receiver is continued by the operation of the pump, its spring becomes so weak, that it is not able to overcome the cohesion of the bladder to the plate, the weight of the bladder, and the resistance occasioned by its being stretched. The larger the hole is, over which the bladder is laid, a proportionably greater force is exerted upon it by the included air in order to lift it up; and yet the aperture of the hole cannot be made very large, because the pressure of the incumbent air would either burst the valve, or so far force it down into the cavity as to prevent its lying flat and close upon the plate. In order to avoid these inconveniences, instead of one hole, Mr. Smeaton makes use of seven, all of equal

size and shape, one being in the centre, and the other fix round it, so that the valve is supported at proper distances by a kind of grating, formed by the solid parts between these holes, and resembling a honeycomb; and that the points of contact between the bladder and grating may be as few as possible, the holes are hexagonal, and the partitions are filed almost to an edge. The breadth of these hexagons is $\frac{1}{3}$ ths of an inch, and consequently the surface nine times larger than common; and as the circumference is three times greater than that of the common valve, and the cohesion to be overcome is, in the first moment of the air's exerting its force, proportional to the circumference of the hole, the valve over any of these holes will be raised with three times more ease. Besides, the raising of the valve over the centre-hole is aided on all sides by those that are placed round it; and as they all contribute as much to raise the bladder over the centre hole, as the air immediately acting under it, the valve will be raised with double the ease already supposed, or with a sixth part of the force commonly necessary. After the bladder begins to rise, it will expose a greater surface to the air underneath, which will cause it to move more easily.

The other defect in the common construction would still hinder the rarefaction from being carried on beyond a certain degree. For as the piston does not fit so closely to the bottom of the barrel, as totally to exclude the air, this air, as the piston rises, will expand itself; and pressing upon the valves in proportion to its density, hinder the air within the receiver from coming out. Hence, if the vacancy were equal to the 150th part of the capacity of the whole barrel, no air could pass out of the receiver, when expanded 150 times, though the piston were constantly drawn to the top; because the air in the receiver would be in *equilibrium* with that in the barrel, when in its most expanded state. In order to obviate this inconvenience, Mr. Smeaton shut up the top of the barrel with a plate, having in the middle a collar of leathers, through which the cylindrical rod works that carries the piston. The external air is thus prevented from pressing upon the piston; but for the discharge of the air that passes from below through the valve of the piston, there is a valve applied to the plate at the top, which opens upwards. By this construction, when the piston is put down to the bottom of the cylinder, the air under it will evacuate itself so much the more, as the valve of the piston opens more easily, when pressed by the rarefied air above it, than when pressed by the whole weight of the atmosphere; and as the piston may be made to fit as nearly to the top of the cylinder as it can to the bottom, the air may be rarefied as much above the piston, as it could before have been in the receiver. Hence it follows, that the air may now be rarefied in the receiver in duplicate proportion of what it could be upon the common principle. By this construction, the pump, consisting of a single barrel, may be worked with more ease than the common pump with two barrels, because the pressure of the outward air is taken off by the upper plate; and when a considerable degree of rarefaction is desired, it will produce it more speedily.

Mr. Smeaton has also contrived a new gage, which measures the expansion with certainty, to much less than the 1000th part of the whole. It consists of a bulb of glass, in shape resembling a pear, and sufficient to hold about half a pound of quicksilver. It is open at one end, and the other is a tube hermetically sealed at top. A scale divided into parts of about $\frac{1}{16}$ th of an inch each, and answering to a 1000th part of the whole capacity, is annexed to it. This gage, during the exhaustion of the receiver, is suspended in it by a slip-wire. When the pump is worked as much as is thought necessary, the gage is pushed down, till the open

end is immersed in a cistern of quicksilver placed underneath. The air being then let in, the quicksilver will be driven into the gage, till the air remaining in it becomes of the same density with the external; and as the air always takes the highest place, the tube being uppermost, the expansion will be determined by the number of divisions occupied by the air at the top. See GAGE.

This ingenious artist has succeeded so well in his construction of the air-pump, as to be able to rarefy air about 1000 times; whereas the best of the common air-pumps, esteemed good in their kind, and in complete order, never rarefied it above 140 times. Mr. Smeaton's air-pump acts also as a condensing engine, by the very simple apparatus of turning a cock; see CONDENSER. This air-pump is thus easily made an universal engine, for shewing any effect arising from an alteration in the density or spring of the air; and with a little addition may be made to shew the experiments of the *AIR-FOUNTAIN, AIR-GUN, &c.* Phil. Trans. vol. xlviii. p. 415—423.

A perspective view of the principal parts of this pump is exhibited in *Plate VI. Pneumatics, fig. 45.* A is the barrel, B the cistern, in which is included the cock, with several joints, which are covered with water to keep them air-tight; and a little cock to let the water out of the cistern is marked G. C c c is the triangular handle of the key of the cock, which, by the marks on its arms, shews how it must be turned, that the pump may produce the effect desired. D H is the pipe of communication between the cock and the receiver. E is the pipe that communicates between the cock and the valve, on the upper plate of the barrel. F is the upper plate of the pump which contains the collar of leathers d, and V is the valve, which is covered by the piece f. G I is the syphon-gage, which is screwed on and off, and adapted to common purposes. It consists of a glass-tube hermetically sealed at c, and furnished with quicksilver in each leg, which, before the pump begins to work, lies level in the line a b; the space b c being filled with air of the common density. When the pump exhausts, the air in b c expands, and the quicksilver in the opposite leg rises, till it becomes a counterbalance to it. Its rise is shewn upon the scale I e, by which the expansion of the air in the receiver may be nearly estimated. When the pump condenses, the quicksilver rises in the other leg, and the degree may be nearly judged of by the contraction of the air in b c; marks being placed at $\frac{1}{2}$ and $\frac{3}{4}$ of the length of b c from c, which shew when the receiver contains double or treble its common quantity. K L is a screw-frame to hold down the receiver in condensing experiments, which takes off at pleasure, and is sufficient to hold down a receiver, the diameter of whose base is seven inches, when charged with a treble atmosphere; in which case it acts with a force of about 1200 pounds against the screw-frame. M is a screw that fastens a bolt, which slides up and down in that leg, by means of which the machine is made to stand fast on uneven ground. The structure, connection, and relative uses of the several parts of this pump will be further perceived in the following account of Smeaton's air-pump, constructed and improved by Mr. Nairne.

A perspective view of it appears in *Plate VI. Pneumatics, fig. 46.* A, A, are the two barrels of a simple double-barrelled air-pump; the tube g g conveys the air from the receiver placed in the pump-plate T, and the cock Q serves to cut off the communication between the receiver and the barrels, A, A, when the exhaustion is completed. In the front of the pedestal Z is a screw, serving to admit air into the barrels, that the valves may not be pressed after the cock Q is turned; the button i readmits air into the

receiver; the syphon-gage *y* is made in the usual manner; but the cisterns *x, x*, prevent the gages from being dirtied by the oil, on the readmission of the air. The large barrel *C* has a solid plunger, worked by the rod *R*, which passes through the collar of leathers *u*; for the construction of which, as well as the internal structure of the barrel *C*, see *fig. 47*.

This is a vertical section of the barrel, &c.; the top or cup *U* screws on to the screw *u*, and the cavity *b* is made conical; the holes *e, e*, are made just large enough to let the piston rod pass freely; the cavity *b* is filled with circular greased leathers, through the center of which a hole is made, that barely admits the piston rod to pass; these leathers are croured into *h*, and three or four thicknesses of them are left above the surface, *f*; and consequently, when the cup *U* is screwed down, these leathers are forced into the smaller part of the conical hollow *b*; and therefore they bind as much or as little as is requisite on the piston rod. The head *a* is screwed with eight screws on the upper flaunch or part of the barrel *C*; the bottom *B* screws on the lower flaunch or lower end of *C*; the plug *D* is accurately ground into a conical hole in the bottom *B* and has the lever *L* standing at right angles. As the whole nicety of the exhaustion of this air-pump depends upon this part, it should be very particularly described. The lever *L* is represented as standing to the left hand; and the hole *2* with its valve *1* is seen in connection with the pipe *P*, and consequently with the receiver; see the horizontal section *L D P*. But if the lever *L* is brought towards the word "CLOSED," the hole *2* with its valve *1* has moved onwards towards *D*; no hole is opposite to the hole of *P*, and consequently all communication between the receiver and the inside of the barrel *C* is cut off; but upon moving the lever *L* more towards the right hand, the hole *3* having "NO VALVE" will be in connection with *P*, and consequently there will be a direct or uninterrupted passage between the receiver and the inside of the barrel *C*. Upon attentively inspecting the section, it will be perceived by the directions in which the valves open and close, and the position of the passages which are drilled through the thickness of the barrel, that the ascent or descent of the solid plunger *N* equally exhausts the pipe *P*, and consequently the receiver. It must be remarked, that the valves exhibited in the section are drawn like lids of boxes, with joints for the purpose of shewing in what direction they open; but in reality the valves are made of oiled silk; and as on the nice construction of these the good action of the pump much depends, the best mode of making them will be illustrated in the section, *fig. A A*, which shews the plug *D*, on which the valve is to be fixed. In the first place, a groove must be turned, of a convenient size, so as to leave a cylindrical knob *F*, whose diameter may be four or five eighths, or more, of an inch; the hole which the oiled silk valve is intended to cover, is made through the axis or center of this knob, as is shewn by the dotted lines *H*; the ring *G* is to fit nicely into the groove, and to be flush with the general surface of the brass; the surface of the knob *F* must be turned away about double the thickness of the oiled silk for the purpose of preserving the oiled silk from injury by the piston's striking it; a slip of oiled silk about the width of four times the diameter of the hole, which it is to cover, must be laid over the hole in the center of the knob *F*, and the ring *G* carefully put in its place and there fixed by two or three screws. *Fig. B B* shews the construction of the reservoir *x x*, (*fig. 46*), for the purpose of keeping the gages clean. The end of the gage *G*, for instance, passes through the bottom of the reservoir *x*, and reaches nearly to the top; and a piece of metal, flat

or like an inverted tea-saucer, is fixed to the top of *x*, *fig. B B*. The oil which comes from the pump through *m* is thrown on the back of the saucer, and running to its edges drops into the bottom part of the reservoir, and thus prevents any filth from getting into the tube *G*, *fig. 46*.

Having described the particular parts of this pump, we shall next explain the mode of working it, so as to obtain the greatest degree of exhaustion. A receiver well ground and made dry, with oil put upon its edge, is to be placed on the pump plate *T*, (*fig. 46*), over the aperture of the pipe *P*; and the lever *L* is to be moved so as to stand under the word "VALVE." By working the piston of the cylinder *C* up and down, from the top to the bottom, the receiver becomes partly exhausted, and the mercury will rise from the cistern *M* up into the tube of the barometer gage *G*; the exhaustion must be continued till it will rise no higher; and turning the lever *L* under the word "CLOSED," the piston must be moved two or three times up and down; let it then be left at the bottom of the barrel *C*; move the lever *L* under the words "NO VALVE," and gently raise the piston to the top of the barrel. As there is now a direct communication between the receiver and the barrel *C*, without the intervention of a valve, the air will expand itself freely into the barrel, and the mercury of the gage will rise; keeping the piston at the top of the barrel, turn the lever again under the word "CLOSED," and repeat the operation as before; unscrew the receptacle for dirty oil *O*, and screw in its place the complete small exhausting syringe *S*; work this a few times, and repeat the operation with the barrel and the lever *L* as before, till the mercury will rise no higher in the gage.

By the process now described, the exhaustion has been made so perfect, that when an open cistern barometer, suspended in the room, has been on the rise, the mercury in the gage *G* has risen within $\frac{1}{100}$ th of an inch as high.

The double-barrelled air-pump *A A* being placed on the same stand, and having a communication with the pump plate *T*, as well as the improved pump *C*, is intended for exhausting large receivers very expeditiously; as both pumps may be worked at the same time; and more especially for preventing the improved pump from being used for trifling experiments, or those where water is made use of. In the pump plate *T* are two holes, situated near each other, one communicating with the double-barrelled, and the other with the improved pump, and serving the purpose of cutting off the communication of either with the receiver at pleasure. Indeed, when the double-barrelled pump is only used, the hole of the pipe *P*, leading to the barrel *C*, should always be carefully stoppered to prevent moisture of any kind from getting into it.

Since the time of Mr. Smeaton the air-pump has received very material improvements; for which we are indebted to the Rev. Mr. Prince, of Salem, in North-America; and to Mr. Cuthbertson, late of Amsterdam, and since settled in London.

Mr. Smeaton's success in facilitating the opening of the valves, at the bottom of the barrel and in the piston, led Mr. Prince to conceive, that if these valves were entirely removed, and the remaining air in the barrel could be more perfectly expelled, the rarefaction might be carried still farther. Upon this plan he constructed his air-pump. He removed the lower valve, and opened the bottom of the barrel into a cistern on which it was placed, and which had a free communication with the receiver; for the valve on the upper plate, at the top of the barrel, constructed like Mr. Smeaton's, made it unnecessary that there should be any at the bottom, in order to rarefy the air in the receiver. The cistern was made deep enough to admit of the piston's descending into it below the bottom of the barrel. If the piston be solid, that is, without a valve, when it enters the

barrel and rises to the top-plate, which is made air tight with a collar of leathers, like Smeaton's, it forces out all the air above it; and as the air cannot return into the barrel on account of the valve in the top-plate, when the piston descends, there will be a vacuum between it and the plate; every thing being supposed perfect. But in working the pump, the piston is not allowed to descend entirely into the cistern so far as to leave the bottom of the barrel open; but it descends below a hole in the side of the barrel near the bottom, which opens a free communication between the barrel, cistern, and receiver. Through this hole the air rushes from the cistern into the exhausted barrel, when the piston has dropped below it; and by its next ascent this air is forced out as the other was before. If the capacity of the receiver, cistern, pipes, &c. below the bottom of the barrel, taken together, be equal to the capacity of the barrel, half the remaining air will be expelled by every stroke. But as the working of this pump with a solid piston would be laborious, on account of the resistance it would meet with in its descent from the air beneath, though it would be lessened by every stroke as the air became more rarefied, Mr. Prince pierced three holes in the piston at equal distances from each other, and by a circular piece of bladder, tied over the top of the piston, formed a kind of valves over the holes, which opened with sufficient ease to prevent any labour in working the pump, by allowing the air to pass through the piston in its descent. The escape of the air does not, however, depend upon a passage through the piston into the barrel; for when the air, weakened by rarefaction, cannot open this valve, it will still get into the barrel when the communication is opened by the hole at the bottom. This piston will therefore descend as easily as any other, nor will the valves impede the rarefaction. By this construction the valves, made to open with more ease by Mr. Smeaton, are rendered unnecessary for rarefying the air; and that at the bottom of the barrel is entirely removed; the valve on the top plate being the only one necessary in rarefying the air.

Having set aside the valves, which partly prevented the air from entering the barrel above the piston, Mr. Prince's next attempt was to expel the air more perfectly out of the barrel than Mr. Smeaton had done, by making a better vacuum between the piston and the top plate, so that more of the air might be allowed to expand itself into the barrel from the receiver. Mr. Prince also contrived to connect the valves on the top plate with the receiver occasionally by means of a pipe and cock, by the turning of which the machine might be made to exhaust or condense at pleasure. In order to remove the pressure of the atmosphere from the valve on the top plate, so that this valve might open as easily as the piston valve, he connected with the duct on the bottom piece, which conveys the air from the valves to the cock, a small pump of the same construction as the large one; having the barrel opening into the cistern, the piston rod, which is solid, moving through a collar of leathers, and a valve near the top, through which the air is forced into the atmosphere. This pump with one barrel is called the valve-pump; its chief use being to rarefy the air above the valves, or to remove the weight of the atmosphere from them. When this valve pump is used, the passage through the cock is shut up; and, therefore, instead of placing three ducts at equal distances round the cock in the manner of Mr. Smeaton's, Mr. Prince divided the whole into five equal parts, leaving the distance of one-fifth part between the ducts leading from the cistern and the valves to the cock, and two-fifths between each of these and the one leading from the cock to the receiver. By this adjustment, when the communication is open between the receiver and the

valves for condensation, the other hole through the cock opens the cisterns to the atmosphere; but when the communication is made between the cisterns and the receiver for exhaustion, a solid part of the key comes against the duct leading to the valve, and shuts it up, and the air which is forced out of the barrel passes through the atmosphere into the valve-pump; for the valve of the small pump may be kept open while the great one is worked.

Upon this construction, the pump with two barrels may be made like the common pump, which cannot be conveniently done where the lower valve is retained. In this pump the pistons do not move the whole length of the barrels; an horizontal section being made in them a little more than half way from the bottom, where the top-plates are inserted. The pump is thus made more convenient and simple, as the head of it is brought down upon the top of the barrels in the same manner as in the common air-pump. The barrels also stand upon the same plane with the receiver plate, and this plane is raised high enough to admit the common gage of 32 or 33 inches to stand under it without inconvenience in working the pump: as the winch moves through a less portion of an arch at each stroke than it would do if the pistons moved through the whole length of the barrels.

A gage for measuring the degree of condensation having a free communication with the valves, cock, &c. is placed between the barrels in this pump; and the gage is so constructed that it will also serve to measure the rarefaction above the valves when the air is worked off by the valve-pump. It consists of a pedestal, the die of which is made of glass, which forms a cistern for the mercury, a hollow brass pillar, and glass tube hermetically sealed at one end, which moves up and down in the pillar through a collar of leathers. When the pump is used as a condenser, the degree of condensation is shewn by a scale marked on one edge of the pillar; when it is used as an exhauster, the degree of rarefaction of the air above the valves is shewn by a scale on the other edge of the pillar. This gage will also shew, when the valves have done playing, either with the weight of the atmosphere on them or taken off, in the manner which the author has described. The degree of condensation may be also measured by the number of strokes of the winch. For the purposes of great condensation, Mr. Prince has fitted a condenser of a smaller bore than the barrel of the great pump to the cistern of the valve-pump, to be screwed on occasionally. Or, without this condenser, the valve-pump may be adapted to the purpose by being made a little larger, and by having a plate made to screw into the bottom of the cylinder, with a valve on it opening into the cistern; a hole must be made to be opened on the same occasion near the top of the cylinder, to let air in below the piston when this is drawn up above it.

The common gage, which is generally placed under the receiver-plate, is placed in the front of this pump, that it may be seen by the person who works it, and that the plate may be left free for other uses. The plate is so fixed to the pipe leading to the cock, that it may be taken off at pleasure, and used as a transferrer; and it may also serve for other purposes.

The head of this pump is made whole, except a small piece on the back, where the wheel is let in; and the wheel is freed from the piston-rods by pushing it into the back part of the head, and it is kept in its place by a button screwed into the socket of the axis behind. By this apparatus the piston-rods are dislodged from the wheel, and let down into the cisterns, when the pump is not used; and in these cisterns they may also have the advantage of being covered with oil. The principal joints of this pump are sunk into sockets, that

the leathers which close them may be covered with oil to prevent leaking. The lower part of the pump is fitted with drawers to contain the necessary apparatus.

A perspective view of a double-barrelled pump, made by Mr. Jones, according to the construction of Mr. Prince, may be seen in *Plate vii. Pneumatics, fig. 48.* A, A, are two brass barrels in which the pistons move; the barrels communicate with the receiver placed on the pump by means of the pipe B C, and canal D E; the rods of the pistons are seen at F, G; each of these is connected with a rack or piece having teeth on one side. At I there is a wheel, whose teeth are laid hold of by those of the rack; so that by turning the handle H the pistons are alternately raised or depressed, and the air is exhausted out of the receiver K L, the tube B C, and the canal D E, which communicate with one another. At the top of each barrel is a plate, on which is a box *m n*, containing a collar of leathers; through this the cylindrical part of the piston rod moves, air-tight; *o o* is the place of the valve on the top plate, into which a pipe is soldered that conveys the air from the valves to the duct, passing under the valve-pump P, which is designed for preventing the pressure of the atmosphere from acting on the valve of the top plate. Q is the piston rod of this pump, and R the handle by which it is worked. Y is a cock to cut off occasionally the communication between the receiver and the working parts of the pump. At S is a screw, which closes the orifice of the canal D E, by unscrewing which the air may be admitted when required. Z is an oil-vessel for receiving the oil driven over by the action of the pump; and there should be always a small quantity of oil in the cups of the boxes *m, n*, that hold the collar of leathers through which the piston rods move; *a b c* is the barometer-gage; *d e* the box or cistern containing the mercury; and there is a divided box-scale affixed to the tube, for ascertaining the rise or fall of the mercury; a small ivory tube encompasses the lower end of the glass tube, and floats upon the quicksilver in the cistern; the upper end of this is always to be brought to coincide with the lower division of the box scale, by means of the screw under the cistern; and when it thus coincides, the divisions on the scale give the true distance from the surface of the mercury in the basin. The key *f* serves for tightening or loosening the screws of the pump. When either piston is down, in the operation of this pump, there is a free communication from the receiver through the tubes and the canal to the part of the barrel above the piston; when the piston rises, it forces out the air above it through the valve in the top plate; and as this valve prevents the air from returning into the barrel, when the piston descends, a vacuum is formed between it and the under surface of the top plate; as soon, therefore, as the piston has descended below the holes communicating, by the tubes and pipe, with the receiver, the air rushes into the exhausted barrel; on the next ascent of the piston, this air is forced out as before. To prevent the piston from meeting any resistance in its descent, there is a valve in it through which the air passes as the piston descends; but the air does not necessarily depend upon a passage through the piston in order to get into the barrel. By these means the piston descends as easily as in any other construction, while the valve in it does not impede the rarefaction. The valve pump P is, as we have observed, used for taking off the pressure of the atmosphere from the valve on the top plate of the pump, and for forming a more perfect vacuum between this plate and the piston, that nothing may prevent this instrument from exhausting as far as its expansive power will admit. The barometer gage *a b c*, serving to measure the exhaustion of the receiver, consists of a tube, divided by an annexed scale

of inches and fractional parts of an inch, whose higher orifice communicates with the receiver, and the lower is immersed in a cistern of mercury. Before any exhaustion has taken place the mercury in the tube and cistern is upon the same level; and after any number of turns of the handle of the pump, the air in the tube and receiver is equally rarefied, and the mercury will ascend in the tube till the weight of the column above the surface of that in the cistern, and elasticity of the air in the receiver, taken together, be equivalent to the weight of the atmosphere; and if the altitude of the column is equal to the standard altitude, the vacuum in the receiver, and that above the mercury in the barometer, are the same. For an account of the syphon-gage, occasionally substituted for the barometer gage, and the pear gage; see GAGE.

In a contrivance, suggested by an ingenious workman of the late Mr. Adams, and annexed to the pumps constructed by Mr. Jones, one of the lower flexible oil-skins, or leather valves in the two barrels, is attached to a brass ring, which is allowed an interval of motion of $\frac{1}{15}$ th of an inch; a long wire is fixed to a bar over the diameter of the ring, which wire passes along the body of the piston and rod through a collar of leathers in the piston. By the friction of these leathers upon the rod, as they move up and down, the lower valve is occasionally raised and depressed; and thus a communication is opened with the barrel and receiver, and of course the exhaustion is carried to as great a degree as the nature of the air itself appears to admit. By a comparison of the height of the mercury in a good barometer tube, Mr. Jones did not observe the $\frac{1}{100}$ th of an inch difference between this and that of the barometer gage to the pump; and consequently the rarefaction was about 1200 times; and hence he concludes that it was equal in power to that of Mr. Cuthbertson or any pump whatever.

We shall now describe more minutely the parts of which Mr. Prince's improved air-pump consists. *Fig. 49. Plate vii.* represents a perpendicular section of one of the barrels, the two cisterns, condensing gage, &c.; where A B is the barrel, C D is the cistern on which it stands, *a a a a* the leathered joint, sunk into a socket, and buried in oil; E F is the piston, with the cylindrical rod passing through a collar of leathers, G H, in the box H I. K shews the place of the valve on the top plate K, covered by the cross piece M M, into which is soldered the pipe O O, that conveys the air from the valves to the duct going under the valve pump, as may be seen in *fig. 51*: *o* is part of the said duct; *p* is the joint sunk into a socket in the cross piece P P, which connects the cisterns, and has a duct through it leading to them. Into this duct open the ducts *q* and *r*, the first leading to the gage in front of the pump, and the other to the cock and receiver. The other barrel is left out of the figure, except Q, which is the top of it brought down out of its place for the purpose of shewing the top plate that shuts up the barrel, separated from the box, which contains the collar of leathers. S is one of the holes in the plate over which the valve lies, and which is covered by R in the cross piece. V V is the piston shewing the valve open on the top, which is to prevent labour when the pump condenses. W X is the cistern, in which is more distinctly seen the shoulder for the leather, which closes the point between this and the barrel, and also the socket in which the oil lies over the leather. Y Z is the condensing gage, with the orifice of the tube raised above the surface of the quicksilver; *e e* is the collar of leathers, through which the glass tube moves; and *i* is a small pipe coming up through the quicksilver to form a communication between the valves and the gage. In *fig. 50.* is seen the upper surface of the top

plate which closes the barrel, being folded into it, shewing the place of the valves over the three small holes. *Fig. 51* is a perpendicular section of the bottom-piece, pipes, valve-pump, cock, &c. at right angles with the other section, *fig. 49*. The button *o* is screwed here into the top instead of the gage. *CD* is the valve-pump and cistern, *e* the place of the valve, under the cup; *EF* the cock, shewing the duct through it leading to the atmosphere; *GH* the pipe leading from it to the stem of the receiver plate, in which is the cock *I*, to shut up the duct when the plate is used as a transferrer. *K* is the plate; *L* a piece to shut up the hole, into which tubes, &c. are occasionally screwed to perform experiments without removing the plate. The dotted line at *O* shews the place of the screw which presses the plate against the pipe; *PQ* the pipe and common gage standing in front of the pump. *Fig. 52* is a horizontal section of the cock, and pieces containing the ducts leading from it to the receiver, the cisterns and the valves on the top of the barrels; *AB* the duct, connecting the cisterns together; *CD* the duct leading from the cisterns to the cock; *GH* the duct leading from the cock through the pipe *AB* (*fig. 51*.) to the valves; *DE* the duct through the cock, which occasionally connects the two last mentioned ducts with the duct *EF*, leading from the cock to the receiver; *I* the duct in the cock leading to the atmosphere, which, when connected with the duct at *D*, lets the air into the cisterns and barrels for condensation; the other duct through the cock at the same time connecting *H* and *E*. This duct also, when connected with *E*, restores the equilibrium in the receiver. *K* is part of the duct leading from the cisterns to the gage. The dotted circles shew the places of the pipe and valve-pump on the piece, and *r* the place where the air enters the valve-pump from the duct *GH*, and is thrown into the atmosphere when the pump exhausts. *Fig. 53* shews the under surface of the boxes which contain the collars of leathers with the cross piece which connects them together, having a duct through it, as represented by the dotted line, through which the air passes from the valves into the pipe. This figure is chiefly designed to shew the places in which the valves play, as at *I*. *American Transactions*, vol. i. Boston, 1785. *Nicholson's Journal*, vol. i. p. 121—128. *Adams's Lectures on Nat. and Exp. Philos.* by Jones, vol. i. p. 51—54, p. 153.

The air-pump of Mr. Cuthbertson is so excellent in its structure, and so powerful in its effect, that it claims particular notice and description. A perspective view of it appears in *Plate VIII. Pneumatics*, *fig. 56*. Its two principal gages are screwed into their places; but these need not be used together, except in cases where the utmost exactness is required. In common experiments, either of them may be taken away, and a stop-screw put into its place. When the pear-gage is used, a small round plate, large enough for the receiver to stand upon, must first be screwed into a hole at *A*; but when this gage is not used, this hole must be closed with a stop-screw. When all these gages are used, and the receiver is exhausted, the stop-screw *B*, at the bottom of the pump, must be unscrewed, to admit the air into the receiver; but when the gages are not all used, the stop-screw at *A*, or either of the other two which are in the place of the gages, may be unscrewed for this purpose. In *fig. 57*, *CD* represents one of the barrels of the pump, *F* the collar of leathers, *G* a hollow cylindrical vessel to contain oil; *R* is also an oil-vessel, which receives the oil that is driven with the air through the hole *a a*, when the piston is drawn upwards; and when this is full, the oil is carried over with the air along the tube *T*, into the oil vessel *G*: *cc* is a wire which is driven upwards from the hole *a a*, by

the passage of the air; and as soon as this has escaped, falls down again by its own weight, shuts up the hole, and prevents any air from returning by that way into the barrel; at *dd* are fixed two pieces of brass, to keep the wire *cc* in such a direction as may preserve the hole air-tight. *H* is a cylindrical wire, which carries the piston *I*, and is made hollow to receive a long wire, *q q*, that opens and closes the hole *L*, which forms the communication with the receiver standing on the plate; *m* is part of a pipe, one end of which is screwed into the wire *q q*, that opens, and shuts the hole *L*; and upon the other end, *O*, is screwed a nut, which, stopping in the smaller part of the hole, prevents the wire from being lifted too high. This wire and screw are more clearly seen in *fig. 58*, and *fig. 62*: they slide through a collar of leathers, *r r*, *fig. 58*, and *fig. 61*, in the middle piece of the piston. *Figures 60* and *61* are the two main parts which compose the piston; and when the pieces in *figures 59* and *62* are added to it, the whole is represented by *fig. 58*. *Fig. 61* is a piece of brass, turned in a conical form, with a shoulder or ledge at the bottom; a long female-screw is cut into it, about two thirds of its length: and the remaining part of the hole, in which there is no screw, is about the same diameter as the screw part, except a thin plate at the end, which is of a breadth exactly equal to the thickness of *q q*. That part of the inside of the conical piece of brass, in which no thread is cut, is filled with oiled leathers with holes in them, through which *q q* can slide air-tight; there is also a male-screw with a hole in it, which is fitted to *q q*, and serves to press down the leathers *rr*. In *fig. 60*, *a a a a* is the outside of the piston, the inside of which is turned exactly to fit the outside of *fig. 61*; *b b* are round leathers, about 60 in number; *cc* is a circular plate of brass, of the size of the leathers; and *dd* is a screw, which serves to press them down as tight as is necessary. The male screw, at the end of *fig. 59*, is made to fit the female screw in *fig. 61*. If *fig. 62* be pushed into *fig. 61*, this into *fig. 60*, and *fig. 59* screwed into the end of *fig. 61*, these will compose the whole piston, as represented by *fig. 58*. *H*, in *fig. 57*, represents the same part as *H* in *fig. 58*, and is that to which the rack is fixed. If this, therefore, be drawn upwards, it will make *fig. 61* shut close into *fig. 60*, and drive out the air above it; and when it is pushed downwards, it will open as far as the shoulders *a a* (*fig. 60*.) will allow, and suffer the air to pass through. *A A* (*fig. 63*.) is the receiver plate; *B B* is a long square piece of glass, screwed to the undermost side of the plate, through which a hole is drilled, corresponding with that in the centre of the receiver plate, and with the three female screws *b b c*.

In order to conceive how the rarefaction of the air is effected, suppose the piston to be at the bottom of the barrel, and a receiver to stand upon the plate, the inside of the barrel, from the top of the piston to *a*, is full of air, and the piston shut: when drawn upwards, by the hollow cylindrical wire *H*, it will drive the air before it, through the hole *a a*, into the oil-vessel *R*, and out into the atmosphere by the tube *T*. The piston will then be at the top of the barrel at *a*, and the wire *q q* will stand nearly as it is represented in the figure, just raised from the tube *L*, and prevented rising higher by means of the nut *o*. While the piston is moved upwards, the air will expand in the receiver, and be driven along the bent tube *m*, into the inside of the barrel. Thus the barrel will be filled with air, which, as the piston rises, will be rarefied in proportion as the capacity of the receiver, pipes, and barrel, is to the capacity of the barrel alone. When the piston is moved downwards again by *H*, it will force the conical part, *fig. 61*, out of the hollow part, *fig. 60*, as far as the shoulders *a a*; *fig. 58*

will rest upon *aa*, *fig. 60*, which will then be so far open as to permit the air to pass freely through it, while at the same time the end of *qq* is forced against the top of the hole, and closes it in order to prevent any air from returning into the receiver. Thus the piston, while moved downwards, suffers the air to pass out between the sides of *fig. 60*, and *fig. 61*, and when it is at the bottom of the barrel, will have the column of the air above it; and, consequently, when drawn upward, it will shut and drive out this air, and by opening the hole *L*, give a free passage to more air from the receiver. This process being continued, the air will be exhausted out of the receiver as far as its expansive power will permit: for in this machine there are no valves, as in the common air-pumps, to be forced open by the air in the receiver, which, when its elasticity is diminished, it becomes unable to affect; nor is there any thing to prevent the air from expanding to the greatest degree.

In using this machine for exhaustion, no directions are necessary besides those which relate to common pumps, nor is any peculiar care required to keep it in order, except that the oil-vessel, *G*, be always kept about half full of oil. When it has stood for a considerable time without being used, it will be proper to draw a table-spoonful or two of oil through it, by pouring it into the hole in the middle of the receiver plate, where the piston is at the bottom of the barrel; then, by moving the winch backward and forward to raise and depress the piston, the oil will be drawn through all the parts of the machine; and the superfluous part will be forced out through the tube *T*, into the oil-vessel *G*. Near the top of the cylindrical wire *H*, is a square hole, which is intended to let in some of the oil from the vessel *G*, that the oiled leathers, through which the wire *qq* slides, may always be duly supplied with it.

When the pump is required to condense, either at the time when it exhausts, or separately, the piece which contains the bent tube *T*, must be taken away, and *fig. 64*, put into its place, and fastened by the same screws. In the plate, *fig. 64*, is drawn as it is made for a double-barrelled pump; but for a single barrel, one piece is used, represented by *baa*, the double piece being cut off at the dotted line *aa*. In this piece is a female screw, for receiving the end of a long brass tube; to which a bladder, if sufficient for the experiment, must be tied; or else a glass, properly confined for this purpose, must be screwed to it. Then the air, which is exhausted out of a receiver standing on the plate, will be forced into the bladder or glass connected with the brass tube. But if the pump be double-barrelled, the apparatus, as represented by *fig. 64*, must be used, and the long brass tube screwed into the female screw at *C*.

The two gages are represented in *fig. 65*, and *fig. 66*; the one is the syphon-gage, and the other the barometer or long gage. When these are used, *fig. 65*, must be screwed into the female screw, *cb*, or into that at the other end *c*, *fig. 63*; and *fig. 66* into the female screw *ab*, *fig. 63*.

If it be used as a single air-pump, either to exhaust or condense, the screw *K*, which fastens the rack to the cylindrical wire *H*, must be taken out; then turning the winch till this wire is depressed as low as possible, the machine will be rendered fit to exhaust as a single air-pump; and if it be required to condense, the directions already given with regard to the bent tube *T*, and *fig. 68*, must be observed.

Mr. Cuthbertson has, by a variety of experiments with this air-pump, shewn its great powers of exhaustion. With the double syphon gage, and also with the long gage, compared with an attached barometer, in which the mercury had been repeatedly boiled, the difference between the heights

of the mercurial column proved to be no more than $\frac{1}{8}$ th of an inch, the barometer standing at 30 inches, which gives an exhaustion of 1200 times. On some occasions, when the air was in a very dry state, he observed the difference to be as low as $\frac{1}{16}$ th of an inch, which indicates more than double the rarefaction. See Description of an improved Air-pump, by John Cuthbertson, 8vo. London: for an abstract, Nicholson's Journal, vol. i. p. 128—130.

We shall close our account of the two pumps of Prince and Cuthbertson with the following judicious remarks of Mr. Nicholson (in his Journal, vol. i. p. 131.) on their respective merits and imperfections. "There is no provision to open the upper fixed valve of Prince's greater barrel, except the difference between the pressures of the elastic fluid on each side of the strip of bladder; and this may reasonably be inferred to limit the power of his small pump. In Cuthbertson's pump, the same valve is exposed to the action of the atmosphere, together with that of a column of oil in the oil-vessel. The mischief in either instrument is probably trifling; but in both, the valve might have been opened mechanically. If this were done, the small pump of Prince might perhaps be unnecessary in most states of the atmosphere. With regard to the lower valves, Cuthbertson, by an admirable display of talents as a workman, has insured their action. Prince, on the other hand, has, by the process of reasoning, so far improved the instrument, that no valves are wanted. In this respect, he has the advantage of simplicity and cheapness, with equal effect. The mechanical combination of Cuthbertson's pump reduces the operation to one simple act of the handle: but Prince's engine requires some manipulation with regard to the play of the small pump; though this might have been remedied by a more skilful disposition of the first mover."

"The most perfect scheme for an air-pump, taking advantage of the labours of these judicious operators, seems to be that in which two pistons of the construction of Prince should work in one barrel; one piston being fixed at the lower end of the rod, and the other at the middle. The lower piston must come clear out of the barrel when down, and work air-tight through a diaphragm at an equal distance from the effective ends of the barrel. In the diaphragm must be a metallic valve, of the form of Cuthbertson's lower-valve, but with a short tail beneath, that it may be mechanically opened when the piston comes up. Above the diaphragm must work the other piston, similar to the first; but as it cannot quit the barrel when down, a small portion of the barrel must be enlarged, just above the diaphragm, so that the leathers may be clear in that position. Lastly, the top of the barrel must be closed and fitted with a valve and oil-vessel, according to the excellent contrivance of Cuthbertson."

"If we suppose the workmanship of such a pump to leave the space between the diaphragm and lower piston, when up, equal to one-thousandth part of the space passed through by the stroke of that piston, the rarefaction produced by this part of the engine will in theory bear the same proportion to that of the external air; and the same supposition applied to the upper piston, would increase the effect one thousand times more: whence the rarefaction would be one million times. How far the practical effect might fall short of this from the imperfections of workmanship, or the nature of the air, which in high rarefactions, may not diffuse itself equally through the containing spaces, or from other yet unobserved circumstances, cannot be deduced from mere reasoning without experiment."

It is observed in the Encyclopædia Britannica, (vol. xv. p. 107.) that a construction of the air-pump, similar to that

of Mr. Cuthbertson, was invented, and, in fact, executed, before the end of 1779, by Dr. Daniel Rutherford, afterwards professor of botany in the university of Edinburgh. He made a drawing of a pump, having a conical metal valve in the bottom, furnished with a long slender wire, sliding in the inside of the piston rod with a gentle friction, sufficient for lifting the valve, and secured against all chance of failure by a spring at the top, which took hold of a notch in the inside of the piston-rod, about a quarter of an inch from the lower end, so as certainly to lift the valve during the last quarter of an inch of the piston's motion. He had executed a valve on this principle; but his thoughts were diverted from the further prosecution of the business.

In Phil. Transf. (vol. lxxiii. p. 435,) we have a description by Mr. Cavallo, of an air-pump contrived and executed by Messrs. Haas and Hurter, instrument-makers in London, in the construction of which these artists have revived Guericke's method of opening the barrel-valve during the last strokes of the pump, by an external force; of this pump Mr. Cavallo says, that when it had been long used, it had, in the course of some experiments, rarefied 600 times.

The drawing and description of a new air-pump, acting by means of a quantity of oil in the barrel, and invented by James Sadler, Esq. have been published by Mr. Nicholson, in his Journal, vol. i. p. 441, &c. He says, that it possesses the desirable requisites of simplicity, cheapness, and power; though at the same time he very properly suggests, that the oil, in process of time, may become changed by the circulation, and less fit for the purpose, and probably carry with it bubbles of air. He does not mention its practical effects.

A new air-pump, similar in its principle to those of Mr. Smeaton and Mr. Cuthbertson, has lately been constructed by the Rev. Mr. Little, of the county of Mayo in Ireland. The principal parts of this machine are one barrel and piston, one stop-cock, one valve, and two pipes of communication. It is of a portable size, and so contrived as to be confined in a very small space. The barrel is placed horizontally, and the rack, by which the piston is moved, underneath the barrel; so that the machine may be packed in a box two feet long, 18 inches wide, and seven in depth. It is adapted to the purposes of a condensing as well as of an exhausting engine. As to the effects of this pump, the author informs us, that in several trials of exhaustion, in the months of July, August, and September, 1795, the air being generally very dry, the rarefaction produced, as shewn by the pear-gage, was, five times, between 3000 and 4000: the mercury in the barometer gage standing at the same times always above $\frac{1}{16}$ th part of an inch higher than it stood in a standard barometer of a wider bore, which was filled with mercury made very hot and poured into a hot tube, and the mercury in the reduced barometer-gage sunk below the level of the surrounding mercury. In the other nine trials, the rarefaction, as shewn by the pear-gage, was from 9000 to 26000; when the barometer-gage stood at $\frac{1}{16}$ ths of an inch higher than that in the standard barometer, and sunk in the reduced barometer still lower than before beneath the stagnant mercury. For a particular description and drawing of this instrument, and a minute detail of its practical effects; see Transactions of the Royal Irish Academy, vol. vi. p. 319—391.

The portable or table air-pump differs principally in size and the structure of the gage from the common air-pump described at the beginning of this article. It has two brass barrels, which are firmly retained in a perpendicular situation to the square wooden table on which they rest by a transverse beam, which is pressed upon them by screws at

the top of two pillars. From the hole in the centre of the pump-plate, there is a perforation or canal in a brass piece, to the fore part of the frame of the pump; and from this canal there is a perforation right-angular to the former, passing to the centre of the basis of each barrel. At each of these centres a valve is placed opening upwards to admit the air into the barrels. To each barrel a piston is so fitted that the air cannot pass between it and the sides of the barrel. Each piston has a valve opening upwards, that the air in the lower part of the barrel may escape through them into the common air. They are also connected with a rack, and are raised or depressed by a handle, the lower part of which is fixed to the axis of a cog-wheel, whose teeth lay hold of the rack. One piston is raised and the other is depressed, by the same turn of the handle. The operation of exhausting is the same as in the common pump. Two barrels are advantageous, because they perform the work more speedily, and also because the weight of the atmosphere, pressing upon the rising piston, is counterbalanced by the same weight pressing upon the other piston descending.

Behind the large receiver upon the pump-plate, there is a small plate for sustaining a small receiver. From the hole at the centre of this plate there is a canal communicating with that which passes from the large receiver to the barrels. Under the receiver is a small bottle containing mercury, a small tube filled with mercury and freed from air, and inverted with the open end in the mercury; this is called the short barometer-gage. As the air is taken out of the receiver on this small plate, it is taken at the same time from the larger one; and the descent of the mercury in the tube will point out the degree of rarefaction in the receiver. The mercury, however, does not begin to descend in this tube till near three-fourths of the air have been exhausted; and the air is said to be as many times rarer than the atmosphere, as the column of mercury sustained in this tube is less than the height at which the mercury stands, at that time, in a common barometer. The syphon-gage, which is sometimes used, is a glass tube, bent in the form of a syphon, hermetically sealed at one end and open at the other. The longest leg is four inches, each of which is divided on an adjoining scale, into 20 equal parts. After considerable exhaustion the gage begins to act; and whilst the mercury falls in one leg, it rises in the other; and the quantity of air remaining will be determined by the difference of the height at which it stands in both tubes. This gage is placed in the same situation with the short barometer-gage. See GAGE.

The small single-barrelled pump has two plates, one for receivers, and the other for a short barometer-gage. Its principle is the same with that of the air-pump just described; excepting that it has only one barrel, and that its piston is merely worked by the hand. In general the single-barrelled pump is made only with one receiver-plate and a mahogany basis, to save expences, and with its small apparatus, to be packed in a portable mahogany case.

AIR-PUMP, laws of rarefaction in the receiver of it.—

1. For the proportion of air remaining at any time in the receiver, (supposing no vapour from moisture, &c.) we have the following general theorem.—“In a vessel exhausted by the air-pump, the primitive or natural air contained therein, is to the air remaining, as the aggregate of the capacity of the vessel and of the pump, (*i. e.* the cylinder left vacant in an elevation of the piston, with the pipe and other parts between the cylinder and the receiver) raised to a power whose exponent is equal to the number of strokes of the piston, to the capacity of the vessel alone raised to the same power.” M. Varignon gives an algebraical demon-

stration of this theorem, in the *Memoires de l'Acad. Roy. an. 1693, p. 233, seq. Id. an. 1705, p. 397, seq.*; but it may be also demonstrated pneumatically, thus:—Calling the air remaining after the first stroke, the *first residual*; that after the second, the *second residual*, &c. and remembering that the air in the receiver is of the same density as that in the cylinder, when the piston is raised; it is evident, that the quantity of air in the receiver, is to the quantity of air in the cylinder, pipe, &c. as the capacity of the receiver to that of the cylinder, and consequently, the aggregate of the air in the receiver and the cylinder, *i. e.* the whole primitive air, is to the air in the vessel alone, *i. e.* to the first residual air, as the aggregate of the capacity of the receiver and the cylinder, to the capacity of the receiver alone. After the same manner it may be proved, that the quantity of the first residual air, is to the second residual, as the aggregate of the capacity of the receiver and cylinder to the capacity of the vessel alone. And the same proportion does the second residual bear to the third, and so of the rest.

This may be illustrated by an example. Suppose the capacity of the receiver to be twice as great as the capacity of the cylinder or barrel, then will the capacity of the barrel be to that of the barrel and receiver together as one to three; and the quantity of air exhausted at each turn of the pump is to the quantity of air which was in the receiver immediately before that turn, in the same proportion. So that by the first stroke of the pump, a third part of the air in the receiver is taken away; by the second stroke a third part of the remaining air is taken away; by the third stroke a third part of the next remainder is exhausted; and so on continually; the quantity of air evacuated at each stroke decreasing in the same proportion with the quantity of air remaining in the receiver immediately before that stroke; for it is very evident that the third part, or any other determinate part of any quantity must be diminished in the same proportion with the whole quantity itself. And as the quantity of air in the receiver is by each stroke of the pump diminished in the proportion of the capacity of the receiver to the capacity of the barrel and receiver taken together; each remainder will therefore be always less than the preceding remainder in the same given ratio; or, in other words, these remainders will be in a geometrical progression continually decreasing. To recur to the preceding example; the quantity exhausted at the first turn was a third part of the air in the receiver, and therefore the remaining air will be two-thirds of the same; and for the like reason, the remainder after the second turn will be two-thirds of the foregoing remainder; and so on continually; the decrease being always made, in the same proportion of two to three; consequently the decreasing quantities themselves are in a geometrical progression. And as the quantities exhausted at every turn decrease in the same proportion with these remainders; therefore the quantities exhausted at every turn are also in a geometrical progression. Thus it appears, that the evacuations and the remainders do both decrease in the same geometrical progression. If the remainders decrease in a geometrical progression, it is plain that, by continuing the agitations of the pump, you may render them as small as you please; that is, you may approach as near as you please to a perfect vacuum; but you can never entirely take away the remainder.

From the above reasoning it appears, that the product of the primitive air into the first, second, third, fourth, &c. residuals, is to the product of the first residual into the second, third, fourth, fifth, &c. as the product of the capacity of the receiver and cylinder together, multiplied as

often into itself as the number of strokes of the piston contains units, is to the factum arising from the capacity of the receiver alone, multiplied so often by itself; that is, as the power of the aggregate of the capacity of the receiver and cylinder together, whose exponent is the number of strokes of the piston, to the capacity of the vessel alone, raised to the same power. Consequently, the primitive air is to the last residual, in the ratio of those powers.

2. The number of strokes of the piston, together with the capacity of the receiver and cylinder with the wire, &c. being given; to find the ratio of the primitive air to the air remaining.

Subtract the logarithm of the capacity of the receiver, from that of the sum of the capacity of the receiver and the cylinder; then, the remainder being multiplied by the number of strokes of the piston, the product will be a logarithm, whose natural number shews how often the primitive air contains the remainder required.

Thus, if the capacity of the receiver be 460, that of the cylinder 580, and the number of strokes of the piston 6; the primitive air will be found to the remaining air as 1335 to 1, or 1335 to 10.

For, suppose the capacity of the vessel = v , that of the cylinder and vessel together = a , the number of strokes of the piston = n , and the remaining air = 1. Since the primitive is to the remaining air as a^n to v^n , the primitive air will also be to the remaining air, as $a^n \div v^n$ to 1. Consequently, if the remaining air be 1, the logarithm of the primitive air is $\log. a - \log. v \times n$.

3. The capacity of the receiver and the barrel being given; to find the number of strokes of the piston required to rarefy the air to a given degree.

Subtract the logarithm of the remaining air from the logarithm of the primitive air; and the logarithm of the capacity of the receiver, from that of the aggregate of the capacity of the receiver and cylinder; then, dividing the former difference by the latter, the quotient is the number of strokes required.

Let the primitive air be p , the remaining air r , and the other quantities as before: and we shall have $p : r :: a^n : v^n$; and the $\log. p - \log. r = n \times \log. a - \log. v$; and $n = \frac{\log. p - \log. r}{\log. a - \log. v}$.

Thus, if the capacity of the cylinder be supposed 580, that of the receiver 460, and the primitive air to the remaining air, as 1335 to 10: the number of strokes required will be found to be 6.

4. The proportion of the primitive air to the remaining air, together with the capacity of the receiver and the number of strokes of the piston, being given; to find the capacity of the barrel.

Let the first-mentioned proportion be that of p to r ; the capacity of the receiver, v , that of the barrel, x , and the number of strokes of the piston, n ; then $p : r :: v + x : v^n$; and $\log. p - \log. r = n \times \log. v + x - n \times \log. v$: consequently, $\log. v + \frac{\log. p - \log. r}{n} = \log. v + x$. Hence,

find the logarithm of the capacity of the receiver and barrel, and from this the capacity itself, and subtracting that of the receiver, the capacity of the barrel will be known. For $p : r :: 1335 : 10$, $v = 460$, and $n = 6$: consequently, $\log. v + x = 2.6627578 + \left(\frac{3.1256530 - 1.0000000}{6} \right) =$

$.3542755 = 3.0170333$, the log. of 1040. Consequently, $x = 1040 - 460 = 580$. See Wolf. Elem. Math. tom. ii. p. 289, &c. Cotes's Hyd. and Pneum. Lectures, lect. 13.

To the air-pump belongs a large apparatus of other vessels, accommodated to various kinds of experiments.

Besides the effects, and the phenomena of the air-pump, recounted under the articles *VACUUM*, *AIR*, &c. we may add some others, which, related at large, make the substance of Mr. Boyle's *Physico-Mech. Exper.*—As, that the flame of a candle *in vacuo* usually goes out in a minute, though it sometimes lasts two, but the wick thereof continues ignited after; and even emits a smoke, which ascends upwards.—That a kindled charcoal is totally extinguished in about five minutes, though in open air it remain alive half an hour; that it goes out by degrees, beginning from the top and the outides.—That red-hot iron is not affected by the absence of the air; and yet that sulphur or gun-powder will not be lighted thereby, but only fused.—That a match, after lying seemingly extinct *in vacuo* a long time, revives again upon the re-admission of the air.—That a flint and steel strike sparks of fire as copiously *in vacuo* as out of it; and that the sparks move in all directions, upwards, downwards, &c. here as in the air.—That magnets and magnetic needles are the same *in vacuo* as in air.—That smoke in an exhausted receiver, the luminary being extinct, gradually settles to the bottom in a darkish body, leaving the upper part clear and transparent; and that inclining the vessel sometimes on one side, and sometimes another, the smoke keeps its surface horizontal, after the nature of other fluids.—That the syphon does not run *in vacuo*.—That water freezes *in vacuo*.—That heat may be produced by attrition in the exhausted receiver.—That camphor will not take fire *in vacuo*; and that gun-powder, though some grains of a heap be kindled by a burning-glass *in vacuo*, will not give fire to the contiguous grains.—That glow-worms lose their light in proportion as the air is exhausted, and at length become totally obscure; but upon the re-admission of air, presently recover it all.—That electricity appears like the *Aurora borealis*.—That vipers and frogs swell much *in vacuo*, but will live an hour and half, or two hours; and though seemingly quite dead in that time, come to life again after being some hours in the air.—That snails survive ten hours; and efts or slow-worms, two or three days; leeches five or six.—That fishes will rise up to the top of water, placed under an exhausted receiver, because the air-bladder is expanded, and they are thus made specifically lighter than water; but if the bladder breaks, they sink down to the bottom, and rise no more.—That animals who live in water will not die by exhausting the air out of the receiver, unless they are kept for a considerable time *in vacuo*.—That oysters will remain alive *in vacuo* 24 hours without harm.—That the heart of an eel taken out of the body, continues to beat *in vacuo* more nimbly than in air; and this for a good part of an hour.—That warm blood, milk, gall, &c. undergo a considerable intumescence and ebullition *in vacuo*.—That a mouse, or other animal, may be brought, by degrees, to survive longer in rarefied air, than naturally it does.—That air may retain its usual pressure, after it is become unfit for respiration.—And that silk-worms' eggs will hatch *in vacuo*.

Besides the above-mentioned phenomena, many others are recited by different writers on this subject, and they may be found in the *Philosophical Transactions* of various Academies and Societies, and in the works of Torricelli, Pascal, Mersenne, Guericke, Schottus, Boyle, Hooke, Hauksbee, Duhamel, Mariotte, Hales, Muschenbroek, Grævesande, Desaguliers, Franklin, Cotes, Helsham, Martin, Ferguson, Adams, &c. &c. We shall subjoin for the exercise and amusement of our readers some farther experiments, arranged under distinct heads. For experiments that require peculiar

accuracy, the receiver should not be placed upon leather, either oiled or soaked in water; but the plate of the pump should be made very dry, and the inside of the receiver should be dried and rubbed with a warm cloth. The receiver may then be set upon the plate, and hog's lard, either alone or mixed with oil, be smeared round its outward edge. After performing any experiments, the pump should be cleared of any vapour that has been generated, by exhausting a large receiver to as great a degree as possible; and the vapour that remained in the barrel and pipes will be diffused through the receiver; and if this be large, one exhaustion will be sufficient for clearing the pump. With small receivers the operation should be repeated two or three times. In some of the best pumps, the plate and edges of the receiver are ground so accurately as not to require any leathers; but as the plate is liable to be scratched by setting the receivers upon it, hog's lard or tallow spread upon their edges will be useful. This will prevent the edges from damaging the plate, and will not admit any vapour. When leathers are used for connecting the receiver with a pump plate, and for making the junction air-tight, they are previously soaked in water, oil, or a mixture of melted bees' wax and hog's lard. When experiments are performed that require the use of mercury, a small pipe should be screwed into the hole of the pump plate, in order to prevent any of it, that may be accidentally spilt, from passing into the air-pipe and barrels; which would loosen the folder and corrode the brass.

I. Experiments for shewing the weight and pressure of the air.

1. Exhaust of its air a copper ball, such as C (*Plate V. Pneumatics*, (fig. 26.) the neck of which is furnished with a stop-cock and a screw by means of which it may be fixed to the plate of an air-pump; suspend it, when exhausted, on the end B of one arm of a balance, A B, and lay upon it the small weight *p*, which must be counterpoised by a weight P in the opposite scale of the balance. Turn the cock of the ball, and the air will rush in and render it so much heavier, that the weight *p* must be removed in order to restore the equilibrium. If the ball holds a gallon, it will thus be found that a gallon of air weighs about the sixth part of an ounce. See *WEIGHT OF THE AIR*.

2. Place the small receiver O (fig. 35.) over the hole of the pump plate, and upon exhausting the air, the receiver will be fixed down to the plate by the pressure on its outside; and this pressure will be equal to as many times 15 pounds as there are square inches in that part of the plate which the receiver covers. By turning the cock of the pump and readmitting the air, the receiver will become loose. In order to prove that the receiver O is held down by the pressure of the air, suspend it on the hook of the wire P P passing through the collar of leathers at the top of the receiver M, by which it is covered, and thus let it down on the plate of the pump; and when the air is exhausted from both receivers, the large receiver M will be fixed to the plate by the pressure of the external air; but the small one O will be loose and may be easily removed; on letting in the air, the lesser O will be fixed down upon the plate and the other will be released.

3. Place a small brass or glass vessel A B (fig. 27.) which is open at both ends over the hole of the pump plate, and cover the top of it with the hand; which, when the air is exhausted, will be pressed down by the weight of the external air, so that it cannot be released without difficulty till the air is readmitted.

4. Tie a piece of wet bladder, as *b* (fig. 28.) over the open top of the glass A; when it is dry, let the open end

A over the hole of the pump plate, and as you exhaust the air, the bladder will be pressed down and assume within the glass a concave figure, and at length it will break with a loud report. If a piece of flat glass be laid upon the top of this receiver, and joined to it by a rim of wet leather, the pressure of the outward air will break the glass, when the internal air is exhausted.

5. Immerse the neck *cd* of the hollow glass ball *eb* (fig. 29.) in the water of the phial *aa*; place it on the plate of the pump, and cover it and the hole of the plate with the receiver *A*; exhaust this receiver, and the air will escape by its spring from the ball *eb*, through the neck *cd*, rise in bubbles through the water, and pass off into the external air. When it has done bubbling, turn the cock of the pump, and the air that is admitted will by its pressure on the surface of the water force it up in a jet into the ball *eb*, and almost fill it; the small quantity of remaining air, which occupied the whole ball, and which is now reduced to a small space of condensation, preventing the water from filling the whole cavity of the ball. This experiment may be varied by screwing the end *A* of the brass pipe *ABF* (fig. 30.) into the hole of the pump plate, and placing, by means of wet leather, upon the plate *cd* a tall receiver *G H* close at the top, exhausting the receiver of its air and stopping the pipe by the cock *e*; when this is done remove the apparatus from the pump, set its end *A* in a basin of water, and open the pipe by turning the cock *e*; and the pressure of the air on the water will force it up through the pipe, so that it will ascend in a jet to the top of the receiver. See FOUNTAIN.

6. Set the jar *D* (fig. 31.) containing quicksilver, near the hole of the pump plate, and cover both with the tall open receiver *AB*. Into the plate *C*, placed upon the upper end of this receiver, introduce the open glass tube *g f*, immersed at its lower extremity in the quicksilver of the jar *D*, and screwed by a brass top annexed to it at *b* to the syringe *H*, which is itself screwed to the plate *C*. By the ring *I* draw up the piston of the syringe, and thus exhaust the tube of its air; and the quicksilver in the basin pressed by the undilated air of the receiver *AB* will ascend in the tube. That this ascent is owing to the pressure of the air, and not to what some have called suction, may be evinced by exhausting the receiver of its air, which will cause the quicksilver to descend into the jar, and by readmitting the air, which will raise it again in the tube, although the piston of the syringe be not moved. If the tube be about 32 or 33 inches high, the quicksilver will rise nearly as high in the tube as it stands at that time in the barometer. If the syringe has a small hole at *m*, and the piston be drawn up above that hole, the air will pass through it into the syringe and tube, and the quicksilver will immediately fall down into the jar.

7. Place the jar *A* (fig. 32.) with quicksilver in it on the pump plate, cover it with the receiver *B*, and push the open end of the glass tube *de* through the collar of leathers in the brass neck *C*, almost down to the quicksilver in the jar. Exhaust the receiver *B* of its air, and the tube *de*, which is close at the top *f*, will at the same time be exhausted. When the receiver has been well exhausted, push the open end of the tube into the quicksilver of the jar; and though the tube be exhausted of its air, the quicksilver will not rise in it, because there is no pressure on the surface of that in the jar. But upon admitting the air into the receiver, the quicksilver will immediately rise and stand as high as it did in consequence of the action of the syringe in the preceding experiment.

These two last experiments not only exhibit the weight and pressure of the air, but they also shew that these are increased or diminished in proportion to the increase or decrease of the air's depth. See BAROMETER and TORRICELLIAN Experiment.

8. Join the two brass hemispheres *A* and *B* together (fig. 36.) by the interposition of a wet leather, with a hole in the middle of it; then screw the end *D* into the plate of the pump, and turn the cock *E* of the pipe, *CD*, communicating with the hemispheres; and having exhausted the air, turn the cock so as to stop the pipe. Having removed it from the pump, screw at the end *D*, the piece *Fb*; and two strong men pulling at the handles *g* and *h* will find it difficult to separate the hemispheres; for if the diameter be four inches, they will cohere together with a force equal to 188 pounds, the area being equal to the square of the diameter multiplied by .7854, and the pressure on every square inch being 15 pounds; *i. e.* $16 \times .7854 \times 15 = 188.496$ pounds. If they be suspended by either of the rings on the hook *P* of the receiver *M* (fig. 35.), and the receiver be exhausted of its air, they will separate of themselves.

9. Set the square phial *A* (fig. 37.) upon the pump plate, and cover it with the wire cage *B*; then placing it under a close receiver, exhaust the receiver and the phial which has a small hole under a valve at *b* of their air; and the air upon its readmission into the receiver, being prevented from passing into the phial by the valve *b*, will break it into a number of pieces by its pressure. Quicksilver may be also forced into wood, and made to pass through it by the pressure of the air.

II. Experiments for shewing the elasticity or spring of the air.

1. Place a bladder, containing a small quantity of air and well tied up, under a receiver; and when the receiver is exhausted, the air will expand and fill the bladder so that it will appear as if it were blown with common air. Upon letting in the air, the bladder pressed by it will be reduced to its original flaccid state. This bladder put into a box under a weight of 20 or 30 pounds, and covered with a receiver, will, upon the exhaustion of the receiver, raise the weight by means of the spring of the internal air.

2. Take the glass ball (fig. 29.) which was filled with water, a small bubble of air at the top of it excepted, and having placed it with its neck downward into the empty jar *aa*, and covered it with a close receiver, exhaust the receiver of its air, and the air-bubble will expand itself, and by its elastic force protrude the water out of the ball into the jar. Or, screw the pipe *AB* (fig. 30.) into the pump plate, and place the tall receiver *G H* upon the plate *cd*; exhaust the receiver, and then remove the apparatus and screw it into the copper vessel *CC* (fig. 38.) half filled with water. Then turning the cock *e* (fig. 30.) and the air confined in this vessel will by its spring force the water through the pipe *AB*, and cause it to form a jet into the exhausted receiver, equal to that which was produced by the pressure of the air in a former experiment; other circumstances being alike.

3. Let the balls annexed to the heads of the hollow glass images (fig. 39.) contain water sufficient to render them specifically heavier than water. Place them under a receiver and exhaust it; and the air in the balls will dilate, force part of the water out, and render the images lighter than water, so that they will ascend. On re-admitting the air, they will descend. Small apertures made in the feet of these images will vary the experiment, and answer the same purpose.

3. Animals that die in an exhausted receiver are evidently oppressed at first as with a great weight, then convulsed, and at last expire in apparent agony. Instead of repeating experiments of this kind, the effect of exhaustion is ascertained by what is usually, though improperly, called the lungs-glass. This consists of a bladder tied round a small tube which passes into a bottle, and sealed so tight, that the air cannot escape any way but through the tube. When this machine is put under a receiver and the air begins to be exhausted, the spring of that, which is contained in the bottle, and which cannot escape, compresses the bladder; and when air is again let in, the bladder expands; and these alternate motions of compression and dilatation have been supposed analogous to those of the lungs. See *fig. 40.*

4. Pour quicksilver into the bottle *A* (*fig. 41.*) and screw the brass collar *c*, of the tube *BC*, into the brass neck *b* of the bottle, and let the lower end of the tube be immersed into the quicksilver, so that the air above the quicksilver may be confined there. Cover this tube, which is open at the top, with the receiver *G* and large tube *E F*, fixed by brass collars to the receiver and close at the top. Exhaust the receiver and its tube; and the air will be thus exhausted out of the inner tube *BC* through its open top *C*; and then the air confined in the bottle *A* will, by its spring, force the quicksilver in the inner tube as it was raised in a former experiment by the pressure of the atmosphere; and thus it appears that the elasticity of the air is equivalent to its weight.

5. Screw the end *C* of the pipe *CD* (*fig. 42.*) into the hole of the pump plate, and open the communication between the three pipes *E*, *F*, and *DC*, and the hollow trunk *AB*, by turning the three cocks *d*, *G* and *H*. Cover the plates *g* and *h* with wet leathers, having holes in their middle, so as to communicate with the pipes; place the close receiver *I* upon the plate *g*; shut the pipe *F*, by turning the cock *H*; and exhaust the air out of the receiver *I*. Shut out the air by turning the cock *d*; remove the machine from the pump; screw it to the wooden stand *L*; and put the receiver *K* upon the plate *h*, on which it will be loose whilst it is full of air; but upon turning the cock *H*, and opening the communication between the pipes *F* and *E*, through the trunk *AB*, the air in *K* will, by its spring, pass from *K* to *I*, till it becomes of equal density in both receivers; and then they will be held down with equal force upon their respective plates by the pressure of the atmosphere, and the force with which *K* was held down will be divided between *K* and *I*. Thus it appears, that a force equal to half the elastic force of common air will act within the receivers against the whole pressure of the common air on their outsides. This instrument is called a double transferrer, and it serves to transfer the air from one vessel into another.

6. Fasten a cork in the square phial *A* (*fig. 37.*) with wax or cement; put it upon the pump plate, cover it with the wire cage *B*, and place a close receiver over the cage. Upon exhausting the receiver of its air, that which was enclosed within the phial will dilate itself, and having no counter pressure on the outside, will break the phial outwards by the force of its spring.

7. Place a shrivelled apple under a receiver, and as it is exhausted, the spring of the air within the apple will plump it out and cause the wrinkles to disappear; but upon readmitting the air, it will return to its shrivelled state.

8. Put a fresh egg, from the small end of which a little of the shell and film is removed, under the receiver; and when the air is pumped out, the small bubble of air contained between the shell and film at the larger end, will dilate

itself, and protrude the contents of the egg into the receiver. If the egg be placed in a jar of water under the receiver, its surface will be covered with bubbles of air in the progress of exhaustion.

9. Warm beer put under a receiver, exhausted of its air, will discharge bubbles, which will rise to the surface, and at length give it the appearance of boiling.

10. A piece of dry wainscot or other wood, being put into warm water and covered with a receiver, will discharge air, as the receiver is exhausted, and exhibit bubbles of air, especially about its ends, because the pores lie lengthwise. A cubic inch of dry wainscot has so much air in it, that it will continue bubbling for half an hour together.

If a piece of wood be made to pass through a plate covering the top of a receiver, with one part exposed to the air and the other immersed in a jar of water under the receiver, and the thumb be put on the top of the wood whilst the pump is working, the air contained in the pores of the wood will rush in bubbles through the water; but if the thumb be taken off, a stream of air will flow in through the wood; and thus by alternately taking off the thumb and placing it on the wood, the influx of the air will be alternately admitted and interrupted. See *AIR* and *ELASTICITY of the Air.*

III. Experiments for shewing the resistance of the air.

1. The machine (*fig. 43.*) consists of two mills, *a* and *b*, of equal weight, and moving independently and freely on their axes. Each mill has four thin vanes or sails, fixed in the axis; those of the mill *a* having their planes perpendicular to the axis, and those of the mill *b* having their planes parallel to it. When the mill *a* turns round in common air, it will suffer little resistance, because its sails cut the air with their thin edges; but the mill *b* is much resisted, because the broad sides of its sails move against the air, when it turns round. Each axle has a pin near the middle of the frame, which passes through the axle and projects a little on each side of it; upon these pins the slider *d* may be made to bear, and thus hinder the mills from going, when the strong spring *c* is set on bend against the opposite ends of the pins. Having set the machine upon the pump plate, draw up the slider *d* to the pins on one side, and set the spring *c* at bend upon the opposite ends of the pins; then push down the slider *d*, and the spring acting with equal strength on each mill will set them at work with equal forces and velocities; but the mill *a* will run much longer than *b*, because it meets with much less resistance. Draw up the slider again, and set the spring upon the pins as before; then cover the machine with the receiver *M* (*fig. 35.*) upon the pump plate; and having exhausted it, push down the wire *P P*, through the collar of leathers in the neck *q*, upon the slider, which disengaging it from the pins will allow the mills to turn round by the impulse of the spring; and as there is no air in the receiver that yields any sensible resistance, they will move for a longer time than in the open air, and when one stops, the other will stop also. Hence it appears, that the air resists moving bodies, and that equal bodies meet with different degrees of resistance, according as they present greater or less surfaces to the air, in the planes of their motions.

2. Put the guinea *a* and feather *b* (*fig. 44.*) upon the brass flap *c*; turn up the flap, and shut it into the notch *d*. Then putting a wet leather over the top of the tall receiver *AB*, which is open at both ends, cover it with the plate *C*, so that the tongue *e d* may hang within the receiver. Then having exhausted the receiver, draw up the wire *f*, and the tongue *e d* will be opened by a piece at its end, and the flap *c*

falling down, the guinea and feather will be observed to descend with equal velocities, and by looking steadily to the bottom of the receiver, to fall to the pump plate at the same instant. When air is in the receiver, the guinea will fall in an instant, and the feather will descend gently and by an indirect motion. This apparatus is sometimes so constructed as to let three guineas with their feathers fall separately at three different times, without taking it off or exhausting the air afresh. See *RESISTANCE of the Air*.

IV. Miscellaneous Experiments.

1. Screw the syringe H (*fig. 31.*) to a piece of lead, weighing at least one pound; pull up the piston, which will cause a vacuum in the syringe, and the air by its pressure will drive back the lead upon it; raising it and counteracting its natural weight. But if the syringe and annexed weight be placed in an exhausted receiver, they will fall upon the piston by their natural gravity, and upon readmitting the air, they will be drove upward again, so that the piston will be at the bottom of the syringe.

2. To a balance AB, *Plate vii. Pneumatics, fig. 54.* suspend a weight of lead, and let it be in equilibrio with a piece of cork. Place this apparatus under a receiver and exhaust the air, and the cork will preponderate; but let the air be admitted, and the equilibrium will be restored. As the air is a fluid, all bodies lose as much of their weight in it as is equal to the weight of an equal bulk of the fluid; and as the cork is largest, it loses more of its absolute weight than the lead, and of course must be heavier in order to compensate this greater loss; but when the air is removed, all bodies gravitate according to their quantities of matter, and therefore the cork, which balanced the lead in air, will appear to be heavier *in vacuo*. A more elegant apparatus for this experiment, consisting of a light glass ball A, and a brass weight B, is exhibited in *fig. 55.*

3. Set a clean receiver upon the plate of a pump, and when you begin to exhaust it, hold a candle to the side of the receiver opposite to your eye, and several colours, resembling a halo, will appear about the candle, which are occasioned by the vapours that arise from the wet leathers and their refraction of the light.

4. Place a lighted candle under a tall receiver, and if it holds about a gallon, the candle will continue to burn about a minute; and its light will gradually decay and at length be extinguished. The smoke of the candle will ascend and form a kind of cloud at the top of the receiver; but upon exhausting it, the smoke will fall down to the bottom; thus shewing, that smoke does not ascend because it is positively light, but because it is lighter than air.

5. Let the pipe represented in *Plate viii. Pneumatics, fig. 68.* be annexed to the top of an open receiver, and the air be exhausted; then place one end of the pipe in the middle of a charcoal fire, and open the cock; and the noxious air of the charcoal will pass through the pipe into the receiver; remove the pipe from it, and let down a small lighted wax taper into the receiver, and it will be immediately extinguished. A mouse or bird let down into the receiver will be killed by the air which it contains. If a candle be let down gently, it will purify the air as it descends.

6. By connecting the wire that passes through the collar of leathers of a receiver with the trigger of a pistol lock, placed under it, exhausting the air, and then drawing the trigger, the flint will strike the steel and produce sparks of fire, which will not be visible as in the open air. Or, if two iron bullets be made red-hot, and one of them be under

an exhausted receiver, it will not appear luminous, like the other which remains in the open air.

7. Set a bell upon a cushion under a receiver on the pump plate; and shake the pump so as to make the clapper strike against the bell, and the sound will be distinctly heard; but exhaust the receiver, and if the clapper be made to strike with great force against the bell, it will make no audible sound; hence it is inferred, that air is necessary for the propagation of sound.

AIR-SHAFTS, among *Miners*, denote holes or shafts let down from the open air to meet the adits, and furnish fresh air. The damps, want, and impurity of air, which occur, when adits are wrought 30 or 40 fathoms long, make it necessary to let down air-shafts, in order to give the air liberty to play through the whole work, and thus discharge bad vapours, and furnish good air for respiration: the expense of which shafts, in regard of their vast depths, hardness of the rock, drawing of water, &c. sometimes equals, nay exceeds, the ordinary charge of the whole ADIT.

Sir Robert Murray describes a method, used in the coal-mines at Liege, of working mines without air-shafts. *Phil. Transf. N° 5.*

When the miners at Mendip have sunk a groove, they will not be at the charge of an air-shaft, till they come at ore; and for the supply of air have boxes of elm exactly closed, of about six inches in the clear, by which they carry it down about twenty fathoms. They cut a trench at a little distance from the top of the groove, covering it with turf and rods disposed to receive the pipe, which they contrive to come in side-ways to their groove, four feet from the top; which carries down the air to a great depth. When they come at ore, and need an air-shaft, they sink it four or five fathoms distant, according to the convenience of the breadth, and of the same fashion with the groove, to draw as well ore as air. *Phil. Transf. N° 39.* See MINING.

AIR-THREADS of *spiders*. See THREADS.

AIR-TRUNK, a simple contrivance by Dr. Hales, for preventing the stagnation of putrid effluvia, and purifying the air in jails and close rooms; which consists of a square trunk open at both ends, one of which is fixed in the ceiling and the other is extended to a considerable height above the roof. The noxious effluvia, ascending to the top of the room, escape by this trunk. Some of these have been nine and others six inches in the clear; but whatever be their diameter, their length should be proportionable, in order to promote the ascent of the vapour. As the pressure of fluids, and consequently of the air, corresponds to their perpendicular altitude, the longer these trunks are, so much the greater will be the difference between columns of air pressing at the bottom and at the top; and of course so much the greater will be their effect. See VENTILATOR.

AIR-VESSEL, in *Hydraulics*, is a name given to those metalline cylinders, which are placed between the two forcing-pumps in the improved FIRE-engines. The water is injected by the action of the pistons through two pipes, with valves, into this vessel; the air previously contained in it will be compressed by the water, in proportion to the quantity admitted, and by its spring force the water into a pipe, which will discharge a constant and equal stream; whereas in the common squirting engine, the stream is discontinued between the several strokes. Other water-engines are furnished with vessels of this kind.

Alcohol

ALCOHOL, *ardent spirit, spirit of wine.* *Alcool, Esprit de vin.* Fr. *Weingeist,* Germ. *Spirito ardens, spirito de vino.* *Acquarzente,* Italian. The term alcohol is applied exclusively by modern chemists, to the purely spirituous part of all liquors that have undergone the vinous fermentation. As this substance bears a very high importance, both as a chemical agent and in its various combinations, we shall bestow upon it considerable attention.

Alcohol is in all cases the product of the saccharine principle, and is formed by the successive processes of vinous fermentation and distillation. All fermented liquors, therefore, agree in these two points; the one, that a saccharine juice has been necessary to their production; and the other, that they are all capable of furnishing an ardent spirit by distillation.

Various kinds of ardent spirits are known in commerce, such as brandy, rum, arrack, malt-spirits, and the like; these differ from each other in colour, smell, taste, and strength; but the spirituous part, to which they owe their inflammability, their hot fiery taste, and their intoxicating quality, is the same in each, and may be procured in its purest state by a second distillation, which is termed in technical language, *rectification*.

We shall refer the reader to the articles of FERMENTATION (*vinous*), DISTILLATION, and the several species of distilled spirits, for an account of the progressive stages in the formation of alcohol; and we shall here take up the subject with the process of rectification or the second distillation, whereby alcohol is brought to that state of purity in

in which its chemical properties are the most conspicuous.

Alcohol, as well as ardent spirits of different kinds, is procured most largely in this country from a fermented grain-liquor, prepared for the express purpose of distillation, from grain, melasses, &c.; but in the wine countries, the spirit is obtained from the distillation of wine; whence the synonymous term, *spirit of wine*. We shall only take the example of brandy, which is the product of the first distillation of wine, and mention the method by which alcohol is procured from it by rectification.

Brandy is a compound of alcohol, water, a colouring extractive matter, and a small quantity of oil. It is to the two last that it owes its peculiar flavour, smell, and appearance, whereby it is distinguished from other distilled spirits. The object of the process of rectification is to separate the first from the other ingredients, and this separation is effected upon the principle that alcohol is the most easily volatilized when a gentle heat is applied, and therefore appears in the first product of distillation, whilst the extractive matter and much of the water remain behind. It is more difficult, however, to get rid of the small portion of oil which brandy contains, as this is soluble in alcohol, and will rise with it in distillation, unless prevented by the means which will be presently mentioned.

The observations of M. Baumé, and his directions for the preparation of alcohol, are so judicious and accurate that we shall here mention them.

The following is the process given by this able chemist: "To procure rectified alcohol, put a quantity of brandy in the water bath of an alembic, and proceed to distillation. Set apart the first product of the distillation when it amounts to about a fourth part of the liquor put into the alembic. Then continue the process till about as much more is obtained, or till the liquor comes over white and milky. Then re-distil the latter product, and mix the first half which comes over with the first part of the former distillation, and continue to distil as long as any spirit comes over. This latter portion may be again distilled, and the first product mixed with the former first products, as before. After each distillation, there remains in the alembic a watery liquor which retains the smell of brandy, but is entirely deprived of inflammable spirit, and is thrown away as useless.

"Having thus procured all the spirit from the brandy, return all the reserved first products to the alembic, and distill with a gentle fire. When about half the liquor has come over, it should be kept apart as pure rectified alcohol; the remainder is to be distilled as long as it is inflammable, and may either be again rectified, or reserved for those purposes where a spirit of inferior strength is required."

The reason given by this judicious chemist for the above process is this: the spirit which first passes over in distillation is the purest, and contains the least portion of gross essential oil; the latter portion, on the other hand, is almost saturated with this oil, and the difference between the two is easily distinguishable when rubbed on the hands; the first product leaves no smell of brandy, but the last gives an odour like the breath of drunkards, who digest their food imperfectly. The quantity of oil, however, varies according to the nature of the brandy; that which is made from wine alone containing the least oil, but that which is procured from wine lees being so full of it as to leave a stratum of the oil swimming on the watery extractive liquor left in the alembic, after all the spirit has been distilled off.

M. Dubuiffon remarks concerning this oil, that the Languedoc brandies contain much more of it than the Cogniac; and that after distilling a large quantity of the for-

mer, the head of the alembic was covered with expanded drops of the oil, which adhered to the vessel. When collected together, and quite cold, they became as stiff as suet, had a chefnut colour, a strong disagreeable taste, and a smell like turpentine.

Various additions have likewise been made to the impure spirit, in order to assist in the separation of this oil. The simplest, and one of the most efficacious is water. This, when added to the oily spirit, turns it milky (as is the case with any other solution of essential oil in alcohol), and by weakening the adhesion between the oil and the spirit, it enables the latter to rise in distillation, unmixed with the former. The chief inconvenience of this addition is, that it weakens the strength of the spirit so much as to require successive rectifications before it can be sufficiently deprived of its watery part.

Chalk, crumb of bread, bran, and other substances, are also added before distillation to the spirit, when oily and ill flavoured; and they all have a good effect in keeping down the matters which contaminate the alcohol, and render the distillation more effectual in purifying it.

Quicklime is still more efficacious, but it much lessens the product of alcohol, alters its nature in some degree, and makes it more penetrating. It would appear, however, that there are some kinds of wine in which the odorant particles are so intimately mixed with the spirituous part, that it is scarcely possible to separate them by simple distillation, however cautiously and skilfully conducted.

The common still with the worm-tube and refrigeratory, is very well calculated for the rectification of spirits, only allowance must be made for the readiness with which ardent spirit, when heated, assumes the state of vapour, and the very great expansion which it then undergoes.

Alcohol, freed from all foreign ingredients but water, and already of considerable strength, may be brought to the specific gravity of 0.825, at the temperature of 60°, by a single distillation, where the heat is moderate and applied very gradually, and the condensation slow. When about a third or half of the spirit is distilled over, the strength of the succeeding portion is diminished, the specific gravity increases, and it becomes more watery, and therefore the first product should be kept apart. This cannot be rendered stronger by any repetition of simple distillation, but it may be still further dephlegmated by means which will be mentioned hereafter.

We shall now proceed to the properties of alcohol.

Alcohol is a colourless transparent liquor, appearing to the eye like pure water. It possesses a peculiar penetrating smell, distinct from the proper odour of the distilled spirit from which it has been procured. To the taste it is excessively hot and burning, but without any peculiar flavour. From its great lightness and mobility, the bubbles which are formed on shaking it subside almost instantaneously, and this is one method of judging of its purity. Alcohol is very easily volatilized by the heat of the hand, it even begins to be converted into a very expandible vapour at the temperature of 55° Fahr. and the quickness of evaporation always produces a considerable cold. It boils at about 165°, and the vapours when condensed return unaltered to their former state. It has never been frozen by any cold, natural or artificial, and hence its use in thermometers to measure very low temperatures.

Alcohol takes fire very readily on the application of any lighted body, the speedier in proportion to its purity. It burns with a pale flame, white in the centre and blue at the edges; this gives but a small degree of heat, and is so faint as to be scarcely visible in bright day-light. It burns with-

out any smoke or vapour, and if strong, leaves no residuum; but if weak, it is extinguished spontaneously, and the watery part remains behind.

Alcohol mixes with water in every proportion. Heat is extricated during the mixture, which is sensible to the hand, even in small quantities. At the same time there is a mutual penetration of parts, so that the bulk of the two liquors, when mixed, is less than when separate. Consequently the specific gravity of the mixture is greater than the mean specific gravity of the two liquors taken apart. The alcohol may be again for the most part separated from the water by distillation with a gentle heat. See GRAVITY (*specific*.)

Owing to the great affinity which subsists between water and alcohol, this latter has the power of precipitating from their solution various salts dissolved in water. Thus, if some strong alcohol be added to a saturated solution of Glauber's salt in water, a coagulum is immediately produced, consisting of the salt separated from the water in a very divided form, whilst the alcohol and water form a chemical union. This precipitation, however, only takes place in solutions of those salts which are insoluble in alcohol. This circumstance has been very ingeniously applied to the analysis of various saline solutions, and especially to the examination of mineral waters. The power of precipitating some of these salts extends to very dilute solutions. Mr. Kirwan, in his valuable work on mineral waters, has found by experiment that selenium may be completely precipitated from water which contains only one-thousandth of its weight of this earthy salt, by any alcohol whose specific gravity is below 0.850. For further particulars on this subject, we must refer the reader to the article; WATERS (*Mineral, analysis of*).

Alcohol is capable of uniting with a great number of substances, a circumstance which renders its use very extensive in a variety of chemical processes and in analysis. These we shall enumerate.

Some of the weaker acids, such as the boracic and tartareous, are soluble in alcohol without any apparent decomposition, and may be again recovered by evaporating the spirit. The stronger acids, however, exercise a very powerful action on alcohol, and produce several very curious and important compounds, particularly that singular liquor called ETHER. See the articles ETHER, OIL OF WINE, and OLEFIANT GAS.

All the alkalies, when pure, may be dissolved in alcohol, but the fixed alkalies, when combined with carbonic acid,

are not soluble in this menstruum. This affords a very convenient method of procuring the caustic fixed alkalies in a state of purity, and by proper management they may be made to crystallize from their spirituous solution. The colour of a solution of alkali in alcohol is always somewhat red, however pure the alkali be, which is owing to a partial decomposition of the spirit. See the articles POTASH and TINCTURE OF SALT OF TARTAR.

Several of the neutral, earthy, and metallic salts, are soluble in alcohol. It is of some importance in chemical analysis to ascertain the degree of solubility of these salts, and many experiments have been made for this purpose.

The first of any importance are those of M. Macquer. He employed a spirit rectified so far, that a phial holding a Paris ounce of distilled water, at the temperature of 45° Fahr. would contain six gros and fifty-four grains of the spirit. The salts which he employed were previously dried with care, so as to expel their water of crystallization. He poured into a matras upon each of the salts half an ounce of the spirit, and set the vessel in a hot sand-bath. When the spirit began to boil, he filtrated it while hot, and then left it to cool. He then evaporated the spirit, and weighed the saline residuums; and from these he inferred the quantity of salt which the spirit had dissolved.

This method, however, cannot be considered as accurate, as some of the spirit must have evaporated during boiling, and some of the salt must have been deposited in the pores of the filter. Neither would the errors produced in this way be uniform, since it appears that some salts are, in a greater proportion than others, more soluble in hot than in cold spirit.

Wenzel also published a series of experiments, in 1777, on this subject. He varied the heat which he employed, according to the solubility of the salt.

He has, however, been guilty of a great omission in not mentioning the specific gravity of the alcohol which he used, but it may be supposed to be nearly the same as that of Macquer.

Lastly, Mr. Kirwan, with that accuracy for which he is so justly distinguished, has given in his treatise on mineral waters, a table of the solubility of certain salts, in which alcohol of different densities is employed, and the temperature properly noticed.

Our readers will find the results of all the above-mentioned experiments in the following Table.

TABLE of the Solubility of SALTS in ALCOHOL.

Salts employed, all deprived of their water of crystallization.	MACQUER.	WENZEL.	KIRWAN.				
	Soluble in 288 grs. of Alcohol, of about 0.84 sp. gr.	Soluble in 240 grs. of Alcohol, of about 0.84 sp. gr.	Soluble in 100 grs. of Alcohol, of different specific gravity.—Heat, from 50° to 70°.				
	Boiling heat used.	Heat various, as specified.	Sp. Gr. 0.9	Sp. Gr. 0.872	Sp. Gr. 0.848	Sp. Gr. 0.834	Sp. Gr. 0.817
	Grains.	Grains.	Grains.	Grains.	Grains.	Grains.	Grains.
Nitrated Potash	4	5 boiling heat	2.76	1.	0	0	0
— Soda	15	23 ditto	10.5	6.	—	0.38	0
— Ammonia	108	214 ditto					
— Lime	288						
— Alumine	—	240 at 54°					
— Magnesia	—	694 boiling					
— Silver	84	100 ditto					
— Iron	4	partly decomposed.					
— Copper	48	240 at 54°					
— Zinc	—	decomposed.					
— Cobalt	—	240 at 54°					
— Bismuth	—	partly decomposed.					
Muriated Potash	5	5 boiling	4.62	1.66	—	0.38	0
— Soda	0	0	5.8	3.67	—	0.5	—
— Ammonia	24	17 boiling	6.5	4.75	—	1.5	—
— Lime	288	240 ditto					
— Alumine	—	240 at 54°					
— Magnesia	—	1313 boiling	21.25	—	23.75	36.25	50.
(dried at 120° by Kirwan.)							
— Barytes	—	—	1.	—	0.29	0.185	0.09
Ditto, ditto, crystallized	—	—	1.56	—	0.43	0.32	0.06
Muriated Iron	36	240 boiling					
— Copper	48	240 ditto					
— Zinc	—	240 at 54°					
Corrosive Sublimate.	204	212 boiling					
Acetited Soda	—	112 ditto					
— Lime	—		2.4	—	4.12	4.75	4.88
— Lead	—	240 at 113°					
— Copper	—	18 boiling					
Arseniated Potash	—	9 ditto					
— Soda	—	4 ditto					
Oxalic Acidulum	—	7 ditto					

On examining the comparative results given in the above Table, we cannot consider them as very satisfactory, and in some instances we perceive so striking a difference in the results, that it must depend on some more extensive cause than mere casual error. Probably the degree and continuance of heat employed, in drying the salt and expelling its water of crystallization, must have differed considerably in the respective experiments. It would be useless to attempt to explain the cause of difference in all the results, but this shows the great necessity of attending minutely to every particular in such experiments.

The most important of the salts insoluble in highly rectified alcohol are the following—all the sulphates, both of the alkalis, earths and metals; some of the nitrated metals;

some of the muriated metals; and the carbonated fixed alkalis.

A peculiar colour is perceived in the flame of some of these solutions in alcohol when set on fire. The solution of nitre gives a pale yellow flame, that of boracic acid is a faint green, all the solutions of copper burn with a beautiful bright green, and those of nitrated or muriated strontian shine with a deep blood red.

Ammonia, both pure and carbonated, dissolves readily in alcohol. They are generally united by means of distillation, a moderate heat being sufficient to volatilize each. These combinations are principally employed in pharmacy.

Alcohol will readily unite with the carbonic acid gas, and will take up full its own bulk of it at a medium tem-

perature.—The gas, however, appears to have little or no action on the spirit, since it is expelled from it by heat unaltered.

Neither metals, nor metallic oxyds, nor metallic acids, appear to be in any degree soluble in alcohol.

Sulphur will not contract any union with alcohol by simple digestion either cold or hot; but when they are both reduced to the form of vapour, and then mixed, a true solution is effected, and the result is a very pungent spirit with a strong odour of liver of sulphur, and which becomes milky and deposits the sulphur on dilution with water.

Ardent spirit acts in a slight degree on PHOSPHORUS, and dissolves so much of this inflammable substance as to become slightly luminous in the dark when the solution is dropped into water.

None of the pure earths are soluble in alcohol, and this latter has the power of precipitating lime, barytes, and strontian, from their watery solutions.

It is on the chemical substances belonging to the vegetable kingdom that alcohol exerts its most powerful action as a solvent, and herein consists its very extensive use in pharmacy, in preparing liquors for the table, in some of the arts, and in a very important part of chemical analysis.

Most of the acids belonging to the vegetable kingdom are highly soluble in ardent spirit, such as the tartareous, the citric, the oxalic, and the gallic. In procuring the latter from the gall-nut, alcohol furnishes us with a very elegant and commodious method of separating the acid from the mucilaginous extractive matter with which it is naturally mixed.

The acetous acid, when of the usual strength, simply mixes with alcohol, without producing any decomposition, but chemists have succeeded in forming an acetic ETHER, by employing the acid in its most concentrated state.

Alcohol will readily dissolve SUGAR. Wenzel estimates the quantity at about one-fifth of the spirit. In all the sweet native vegetable juices, such as the sap of the sugar-cane and the maple, or the expressed liquor from the parsnip and beet root, the sugar is mixed with a large quantity of a mucilage very little soluble in alcohol. This furnishes a ready method for separating the purely saccharine part, a method which is much employed in the analysis of various vegetables, for the purpose of ascertaining the comparative quantity of sugar which they may be expected to yield to the manufacturer. The solution, when left to spontaneous evaporation, yields minute crystals of sugar, which are at first brown, and require a further purification.

Ardent spirit is an excellent solvent for essential oils, and in general, for the most odorous and inflammable of the vegetable productions. In the essential oil of a plant resides the Spiritus Rector, or the AROMA, that which gives the exquisite perfume to the rose or jessamine. When these odoriferous plants are distilled with alcohol, it rises strongly impregnated with their scent and flavour, and as it takes up no colouring matter it remains perfectly clear as before. Thus, the common lavender water is alcohol distilled off the lavender plant, and holding in solution the essential oil in which the scent resides. The *Distilled SPIRITS* in pharmacy, are similar preparations of alcohol, containing the flavour of spices, aromatics, or other substances with which it has been distilled. (See OILS ESSENTIAL).

All the RESINS are highly soluble in alcohol, but scarcely, if at all, in water. These solutions have the peculiar colour, and acid taste of the resin which they contain. An addition of water renders them all turbid, and from the pure resinous solutions it precipitates almost the whole of the dissolved

contents in the form of thick flakes. The solution of guaiacum affords an example of this.

The GUM RESINS, which are natural mixtures of gum and resin, yield their resinous part to pure alcohol and but little of their gum; water on the contrary dissolves the gum and leaves the resin; but a mixture of alcohol and water will hold both the ingredients in solution. These preparations are called TINCTURES in pharmacy, and they are of considerable use in containing within a small bulk, the medicinal virtues of larger quantities of the ingredients employed.

Artificial resins, or *Resinous EXTRACTS*, are also made by evaporating to dryness solutions of the resinous parts of several vegetables in alcohol.

CAMPHOR is readily and largely soluble in ardent spirit. This solution, when saturated, will let fall almost the whole of the camphor on the addition of water. Camphor also remarkably assists the solution of the resins.

Solutions of resinous substances in alcohol form the basis of the spirit VARNISHES, which when applied in thin layers over any substance, soon dry from the evaporation of the spirit, whilst the resin remains behind furnishing a smooth thin coating to the surface which they are intended to protect.

The fixed oils, when in their simple state, are entirely insoluble in alcohol, but they may be rendered soluble in this menstruum, either when they have been converted into drying oils by the action of metallic oxyds, or when they are united with alkalies in the form of SOAP. A solution of fine soap in alcohol is perfectly colourless and transparent, and will bear dilution with water without becoming turbid. It is employed in medicine as an external application, and is also a good reagent in the analysis of mineral waters to discover the presence of earthy salts. These decompose the soap by double affinity, and produce curdling.

The effect of alcohol on animal substances bears a considerable resemblance to its operation on the vegetable kingdom.

Muscular fibre and the coagulum of blood are not soluble in this menstruum, but are rendered by it hard, contracted, and incapable of putrefaction.

Albumen is equally insoluble in alcohol and is coagulated by it, probably owing to abstraction of the water which held it in solution. Milk is speedily curdled by ardent spirit of every kind.

Alcohol will dissolve WAX, SPERMACEI, BILIARY CALCULI, and the strong scented animal resins or resinous extracts, such as MUSK and AMBERGRIS. This menstruum, however, does not appear to be so extensively applicable to the analysis of animal substances as of those from the vegetable kingdom.

We have already mentioned that alcohol well rectified may be brought to the specific gravity of 0.825 (at 60° temperature) by a simple distillation, where the process is slowly and carefully conducted, and when only the first third, or half of the spirit which comes over is taken. Chemists have, however, been able to bring it to a higher state of dephlegmation, and consequently a less specific gravity. This is done by adding to the spirit in the alembic or still a quantity of a salt which is itself insoluble in alcohol, and which has such a greedy attraction for water as to be able to separate it from the spirit. Boerhaave recommends for this purpose common salt, hot, dry, and decrepitated. He allows the salt and the spirit to stand together for twelve hours, and then to be heated in a water-bath so as to distil off the spirit

by a very gentle warmth. The salt is left moist in the still, and contains much of the water of the spirit employed. Some recommend burnt alum in the room of salt, but the best addition is very dry, hot, carbonated alkali. A highly dephlegmated alcohol may be prepared in this method without the intermediate process of distillation, only then the spirit will be of a reddish colour, and will contain that small portion of caustic alkali which is always mixed with common carbonated potash, and which is soluble in ardent spirit. The following is Boerhaave's process: "Take a clean glass body containing common spirit of wine, and add thereto one-third of its weight of pure and dry potash, (carbonated potash), which immediately falls to the bottom. Shake the glass, and the salt directly grows moist and begins to dissolve at the bottom, whilst a red thin liquor floats above it; the more the vessel is shaken, the more liquid is the lower part of the salt, and the more distinctly separated from the upper liquor, nor is it ever possible to mix them together, but upon resting they will immediately separate into two liquors."

This process may be continued, he adds, by decanting carefully the upper of the two liquors, (which is the alcohol reddened by a little caustic alkali that it holds dissolved) and adding to it more carbonated alkali, till the portion last added will no longer become wet on shaking, a sign that the alcohol is as fully deprived of water as it is capable of being made by means of alkali. As a proof of the high dephlegmation of the spirit by this method, it may be observed, that if a drop or two of water be added to alcohol in which salt of tartar has long remained dry, the alkali immediately becomes moist, and appears to run unctuous from the sides of the vessel.

If the alcohol be distilled off the alkaline salt with a gentle heat, the first part which comes over will be about the specific gravity of 0.813 to 0.815, at the temperature of 60°, and this is as high a degree of purity as it has been brought to in the accurate experiments made in this country, by Dr. Blagden and others, for the purpose of ascertaining its specific gravity. (See *GRAVITY specific*.)

M. Lowitz, however, asserts, that he has brought alcohol to the specific gravity of 0.791, chiefly by adding, before distillation, a very large quantity of alkali so as almost entirely to absorb the spirit.

After distillation, the wet alkaline salt which is left may be dried, and again used for the same purpose; but Boerhaave asserts, that after repeating the use of the same alkali for a number of times, it becomes changed in its nature, and unfit for the purpose. This would imply a decomposition of the alcohol, which deserves to be further examined.

Various tests have been devised for ascertaining the purity of alcohol, and the proportion of water which it contains. A spirit, which is very free from water will, when set fire to, burn away without leaving any residue; if it is of moderate strength it will burn for a certain time, and then become extinguished, and leave a portion of water more or less considerable, according to the degree of dephlegmation; if, on the contrary, it is very weak and watery, it will not kindle at all. This test, however, is by no means accurate, since the heat of the burning spirit will drive off part of the water which should be left in the residuum. Another test is, to drop a small quantity of spirit on a small heap of gunpowder and kindle it. The spirit burns quietly on the surface of the powder till it is all consumed, and the last portion fires the powder if the spirit was pure, but if watery, the powder becomes too damp and will not explode. This test, also, is very

inaccurate; for if the powder be drenched with even a strong spirit, it remains too damp to be fired; and if it be only barely moistened, any spirit that will burn will inflame it. A better test is, as we have mentioned, to shake the spirit in a phial with some dry carbonated alkali; but the most accurate of all is to ascertain its specific gravity, and compare it with the density of known quantities of alcohol and water, previously mixed for the purpose of giving a standard of comparison. The very extensive and accurate labours on this subject, conducted by Braumé, Blagden, Gouvenain, and other eminent scientific men, belonging with more propriety to the subject of *specific Gravity*.

It remains for us to mention the chemical nature of alcohol, and the appearances which attend its decomposition. The remarkable circumstance of a vegetable product burning away, without the smallest trace of smoke or fuliginous vapour of any kind, had long engaged the attention of chemists. Junker and Boerhaave threw much light on the subject by remarking, that the product of the combustion of alcohol was always a quantity of pure water; and this fact was more fully illustrated by the experiments of the illustrious Lavoisier. The ready evaporation of alcohol, and the ease with which its vapour will fill a large vessel, renders it a dangerous experiment to submit a considerable quantity at once to combustion, in oxygen gas confined in any vessel, but this difficulty was surmounted in an ingenious manner. His first experiment was simply to ascertain the quantity of water yielded by the combustion of a given weight of alcohol. This was performed in the following apparatus, contrived by M. Meusnier. See Plates of *CHEMISTRY*, fig. 10.

E F is a worm, contained in the cooler A B C D. To the upper part of the worm E, the chimney G H is fixed, which is composed of two tubes, one within the other, the inner of which is a continuation of the worm, and the outer one is a case of tin-plate, which surrounds it at about an inch distance, and the interval is filled with sand. At the inferior extremity K of the inner tube, a glass tube is fixed, to which is adopted the argand lamp L M, for burning alcohol.

Things being thus disposed, and the lamp being filled with a determinate quantity of alcohol, it is set on fire; the water which is formed during combustion, rises in the chimney K E, and being condensed in the worm, runs out at its extremity F, into the bottle P. The use of the outer tube G H, and of the sand between it and the inner tube, is to prevent the latter which proceeds from the worm, from being cooled during combustion, which would occasion the water, formed by the burning, to fall back on the lamp instead of passing on into the worm.

This apparatus though not perfect, has the advantage of enabling the chemist to operate with larger quantities than can be admitted in the more accurate experiments on combustion, and by it, the above-mentioned chemists were able to establish the important fact, that the quantity of water collected by the combustion of alcohol *very sensibly exceeds the quantity of the alcohol which is consumed*. The product of water must vary according to the strength of the alcohol, and the care of conducting the experiment; but it is so considerable, that from sixteen ounces of ardent spirit, Lavoisier obtained eighteen ounces and a half of pure water. There is besides, however, a large quantity of carbonic acid produced in this experiment which escapes, and cannot be estimated by this apparatus. Some of this gas unites with the water which is collected, and causes it to precipitate lime-water.

Having thus ascertained in a general way the products

of the combustion of alcohol, Lavoisier proceeded to repeat the experiment, in vessels which might determine the result with accuracy. He employed, for this purpose, a large bell glass, holding from 700 to 800 cubic inches, and inverted over a mercurial trough. A small lamp, filled with a known weight of alcohol, was introduced under the glass swimming on the surface of the mercury, and the wick was armed with a very minute portion of phosphorus. The atmospherical air within the glass was sucked out by a syphon, till the mercury rose to a certain height which was noted; and the phosphorus on the wick being then kindled by a hot iron, the spirit soon took fire. As the air within the glass would be soon consumed, and the inflammation of the spirit stopped, a constant supply of oxygen gas was sent into the glass through a syphon tube, connected with a reservoir of this gas, and which passed under the mercury into the glass where the combustion was going on. Great precaution was required not to let in more oxygen than was barely necessary to keep up the combustion; otherwise the heat, volatilizing part of the spirit, would have filled the glass with vapour of alcohol, and this mixing with the oxygen, would have suddenly exploded by the combustion. In this, as in other respects, the combustion of alcohol strikingly resembles that of pure hydrogen gas. The experiment was at last stopped by the quantity of carbonic acid generated; and on examining the results, (proper corrections being made for pressure and temperature) it was found, that 93.5 grains of alcohol and 110.32 grains of oxygen had been consumed. The products of these were 93.8 grains of carbonic acid and 106.2 grains of water, which last therefore exceeded by 12.7 grains the quantity of alcohol employed. From these data, and from previous experiments (wherein Lavoisier estimated, that 100 grains of oxygen take up 38.88 grains of carbon, for the production of carbonic acid gas; and that the same quantity of oxygen takes up 17.64 grains of hydrogen for the production of water), he concluded the composition of alcohol to be the following,

Carbon	-	-	-	-	-	28	5	3
Hydrogen	-	-	-	-	-	7	8	7
Water already existing in the alcohol						63	6	

100

We may observe, however, that the result of this experiment can only be considered as an approximation towards the truth, since the estimation of the component parts of alcohol here given, does not agree with that which is deduced by the same chemist, from the result of vinous fermentation. Neither is there any light thrown on the mode of union between the component parts, and their degree of oxygenation as they exist in the spirit before combustion.

Alcohol has likewise been more directly decomposed without the accession of oxygen gas. Dr. Priestley procured inflammable air by passing the electric spark through spirit of wine. But the most striking experiments on this subject, performed by this excellent philosopher, were the decomposition of spirit by passing it through red-hot tubes, both of earth and metal. He first transmitted two ounce measures of alcohol, reduced to vapour by boiling, through an ignited porcelain tube, and procured 1900 ounce measures of air, "which was all inflammable *without any mixture of fixed air in it*, and which burned with "a blue lambent flame." (We here quote the very words of the author, which the writer of the article ALCOOL, in the *Encyclopédie Méthodique*, has made to correspond with the experiments of Lavoisier, by adopting the following

singular translation—*M. Priestley, en faisant passer de l'alcool dans un tube d'argile rougi au feu, en a retiré du gaz hydrogène mêlé de gaz acide carbonique.*) Dr. Priestley's next experiments are still more curious, as they determine the existence of carbonaceous matter in spirit of wine. Having found interesting results from the transmission of the vapour of water through a heated copper tube, he repeated the experiments, only substituting the vapour of spirit of wine for that of water. "In this case," he observes, "the vapour of the spirit had no sooner entered the hot copper tube, than I was perfectly astonished at the rapid production of air. It resembled the blowing of bel-lows. But I had not used four ounces of the spirit of wine before I very unexpectedly found that the tube "was perforated in several places, and presently afterwards "it was so far destroyed, that in attempting to remove "it from the fire, it actually fell in pieces. The inside "was full of a black sooty matter, resembling lamp-black." He then varied the experiment by using earthen tubes, placing within them copper filings, and transmitting the vapour of alcohol. The copper was, as before, converted into a black friable substance, obviously produced by the addition of carbonaceous matter furnished by one part of the spirit, whilst the other part appeared in the form of a copious stream of inflammable air. It is however by no means the whole of the charcoal of the alcohol which is detained by the copper, for much of it escapes mixed with the inflammable air in the form of fine soot, giving the gas the appearance of a dense black cloud; and when the tube is strongly heated, this volatilized charcoal will give an uniform black coating to any balloon or large vessel in which the gas is received. Dr. Priestley found some other metals to undergo a similar change by the vapour of alcohol, but none in so striking a manner as copper. On heating some of this charcoal of copper, as he calls it, in oxygen gas, he found it to burn very readily to a certain point, after which the remainder could not be again kindled. The gas produced by the combustion was pure fixed air or carbonic acid.

The excellent Dutch chemists, of the Teylerian institution, Van Marum and colleagues, repeated Dr. Priestley's experiments with great accuracy, and found the same results in every essential particular. They employed, as well as Dr. Priestley, Wedgwood's porcelain tubes, which they inclosed in iron tubes to prevent the sudden action of the fire which is apt to crack them. One extremity of the earthen tube received a small retort in which was put the alcohol, and the other entered a metallic serpentine tube, immersed in a refrigeratory, and provided at the further end with a bottle to receive the gaseous products. In the first experiment which was performed, an ounce and a half of alcohol in vapour had been transmitted through the heated copper, and had produced about six cubic feet of inflammable air.

In the second experiment the heat was greater, and the production of the gas more rapid. In all, the copper was reduced to a black and very friable substance, which fell to pieces between the fingers. The proportion of charcoal added to the copper by the experiments, varied at different times apparently owing to the greater or less rapidity with which the process was conducted. Dr. Priestley had united 446 grains of charcoal to 28 of copper, in one instance; and 508 to 19, in another: but the Dutch chemists found a much less proportion of charcoal, being only an addition of 292 grains to 748 of copper in one case, and in another, 180 of charcoal to 612 of the metal. The great difference in the results is, however, of little consequence in attempt-

ing to ascertain by these experiments the exact proportion of the component parts of alcohol, since a large part of the carbonaceous ingredient escapes the copper, and passes over into the vessels which receive the inflammable air, where it either appears in the form of a fine black foot, or remains permanently united with the hydrogen gas. M. Van Marum likewise collected in the bottle connected with the serpentine a quantity of nearly pure water, about equal to half the weight of the alcohol evaporated by boiling, and of the specific gravity of .996. He does not inform us of the strength of the spirit which he used. He confirmed the other part of Dr. Priestley's experiment by burning the *charcoal of copper* in oxygen gas, and procuring pure carbonic acid, whilst the remaining copper still retained a small portion of carbon which could not be consumed. It is worthy of remark, that the inflammable air produced in the experiments of both these eminent chemists was found to be not much more than twice as light as common air, and it probably bears a considerable resemblance to that species of gas, termed, with great propriety by Mr. Cruikshank, *Gaseous Oxid of Carbon*.

The vapour of alcohol transmitted through earthen tubes forms, in particular circumstances, that singular air which has been named *OLEFIANT GAS*.

The uses to which alcohol is applied are numerous and important. In the arts, it is employed largely as a solvent for those resinous gums which form the basis of numerous varnishes and similar applications.

It possesses in the highest degree the cordial, stimulating, and intoxicating qualities of all distilled spirits, and although the less powerful and more grateful of the spirituous liquors, such as rum, brandy, &c. are more peculiarly devoted to the use of the table, the purer ardent spirit, again sufficiently diluted with water, is employed as the basis of many of the artificial cordial spirits and liquors, to which a flavour and additional taste are given by particular admixtures. Similar to this is the use of alcohol in medicine, where it serves as a solvent for the more active parts of vegetables, under the form of tinctures, and it is also employed as an external application, often with considerable success.

The highly antiseptic power of alcohol renders it particularly valuable in preserving particular parts of the body as anatomical preparations.

The gentle, steady, and uniform heat which it gives during combustion, and the absence of smoke or fuliginous vapour of any kind, make it often a most eligible material for burning in lamps.

As a fluid for thermometers, it has the advantage over mercury in not freezing in any known degree of cold, but from its ready volatility in a moderate heat it cannot be depended on with any accuracy, above 90 or 100 degrees.

The expansibility of alcohol is much greater than water; the former being, in a range of temperature from 30 to 100, $\frac{1}{15}$ th of its bulk, and the latter only $\frac{1}{14}$ th.

The use of alcohol in chemical analysis has been already mentioned. As a solvent for some of the earthy and metallic salts, and a precipitant of others, it is peculiarly fitted to assist in the analysis of mineral waters, and saline substances in general; and in the chemical examination of vegetable and animal matter, it furnishes a solvent of very extensive power, possessed of the valuable advantage to the chemist of producing but little decomposition in the substances which it holds in solution, and therefore enabling him to present them almost exactly with their native properties and distinctive characters.

Boerhaave's Chemistry, vol. ii.—Encyclopédie Méthodique Art. Alcool.—Priestley on Air, 2d edition.—Annales De Chimie, tom. xxx.

ALCOHOL is sometimes also used for a very fine, impalpable powder, which women in the East make use of as a kind of *fucus*. Kohol is a general term applied to a substance applied to the eye-ball, on the inside of the eye-lids, in the form of a powder finely levigated. That which is employed for ornament is called simply *al kohol*, or *isphahany*; when other ingredients, as flowers of olibanum, amber, and the like, are added, on account of some particular disorders, the kohol is distinguished by some appropriate epithet. Dr. Shaw, in his Travels, speaking of the women in Barbary, says, that none of these ladies think themselves completely dressed, until they have tinged their hair and edges of their eye-lids with *al-ku-hol*, the powder of lead-ore. Lady Montague (Letters, vol. ii. p. 32.) takes notice of this custom among the Eastern women; and in her sprightly manner, she supposes our English ladies would be overjoyed to know this secret. This ore used at Aleppo, called Stibium by the ancients, but very different from antimony, is brought from Persia, and is prepared by roasting it in a quince, an apple, or a truffle, then adding a few drops of oil of almonds, it is ground to a subtile powder on a marble. Of late years the lead ore, brought from England, under the name of *Arcifoglio*, has been used instead of the *isphahany*. The quantity of kohol consumed in the East is incredibly great. It has been said by one of their poets, in allusion to the probe used for applying the powder, and the mountains where the mineral is found, "that the mountains have been worn away by a bodkin." This probe or bodkin, called *meel*, is made of ivory, silver, or wood; it is dipped in water, and when a little of the powder has been sprinkled on it, it is applied horizontally to the eye, and the eye-lids being shut upon it, the probe is drawn between them, leaving the inside tinged, and a black rim all round the edge. The Roman Satyrists allude to this custom, as well as that of blackening the eyebrows:

"Illa supercilium madida fuligine tactum
Obliqua producit acu, pingitque trementes
Attollens oculos."

JUVENAL, Sat. ii. v. 67, and Casaubon's note.

The kohol is also used by the men for strengthening the sight, and preventing various disorders of the eye, for which purpose different ingredients are occasionally added. It is also applied to the eyes of children, as soon as they are born, and is renewed at the interval of a few days through the several periods of their adolescence. The use of the kohol is of very ancient date. Passages relative to it, in sacred history, may be seen in Shaw, (Travels, p. 229.), Harmer, (Observations, vol. ii. p. 405.), and Lowth's Notes on Isaiah, chap. iii. v. 16. Harmer conceives that the *redness of the eyes*, as it is in our version, which the dying patriarch mentions in blessing Judah, (Gen. xlix. 12.), is to be explained by this usage. Dr. Russell observes, on a passage in Xenophon referred to by Shaw, that blackening the eyes, though a custom among the Medes, was not at that time in use among the Persians; for Cyrus, among other things, seems to have been surprised at the painted eyes of his grandfather Astyages. Cyropæd. lib. i. p. 8. See Russell's Aleppo, vol. i. p. 111. p. 367. Ed. 1794. From this impalpable powder the name was transferred to other subtile powders, and afterwards to spirits of wine exalted to its highest purity and perfection. See PORPHYRIATION.

ALCOHOL, in the Arabian *distillery*, is when a heavy

slow-paced planet receives another lighter one within its orb, so as to come in conjunction therewith.

ALCOHOL Martis, filings of steel reduced to an impalpable powder, by turning it into rust with urine, then levigating it, and mixing it with a large quantity of water; that is, about a gallon to two pounds and a half of filings. After it has stood a quarter of an hour, the upper part of the water is to be poured off, and evaporated to a dryness. The powder at the bottom is to be put into a paper, in the form of a sugar-loaf, and washed, by gradually pouring in hot water, till it is freed from the urinous salts. With regard to the remaining gross powder, the same process is to be repeated.

Musgrave has a great opinion of this preparation, as a

remedy to bring back the gout from the nobler parts to the joints. He prescribes it thus: take of *alcohol martis* from five to ten grains, *theriaci Andromachi* from half a scruple to one dram, mix these with as much syrup of clove-july-flowers, as is sufficient to make a bolus.

ALCOHOLIZATION, in *Chemistry*, the rectification of a vinous spirit.

This is otherwise called *alcolization*.

ALCOHOLIZATION, according to Starkey, denotes the circulation of a volatile spirit on a fixed alkali, till such time as out of the two arises one neutral body different from both the former. *Alcoholization* is one way of volatilizing alkalis.

ALCOHOLIZATION is also used for **PULVERIZATION**.

Ale

ALE, a popular fermented drink, made from malt and hops; and chiefly distinguished from beer, another potable liquor made from the same ingredients, by the quantity of hops used therein; which is greater in beer, and therefore renders the liquor more bitter, and fitter for keeping. For the method of brewing ale, see BREWING. The brewers also distinguish pale, or fine ale, brown ale, &c. Their several properties, effects, &c. see under MALT-Liquor.

The art of making an infusion of corn, and particularly of barley, similar to our ale, seems to have been known and practised in very ancient times among those people who lived in climates that did not afford grapes. It seems to have passed from Egypt into those western nations, which were settled by the colonies that migrated from the east. The *zythum* and *curmi*, mentioned by Tacitus, as the beverage of the ancient Germans, are supposed by Matthioli to correspond to our ale and beer. Diodorus Siculus says (lib. iv. c. 26. tom. i. p. 350.) that the Gauls, who lived in a country that produced neither grapes nor olives, made a strong liquor of barley, which they called *Zythus*. The natives of Spain, the inhabitants of France, and the aborigines of Britain, used this liquor, under the different appellations of *cælia* and *ceria* in the first country, of *cerevisia* in the second, and of *curmi* in the last; all which names literally denote the *strong water*.

After the introduction of agriculture into this island, ale or beer was substituted for mead, and became the most general drink of all the British nations which practised that art, as it had been of all the Celtic people on the continent. "All the several nations, (says Pliny, H. N. xiv. 29. tom. i. p. 729.) who inhabit the west of Europe, have a liquor with which they intoxicate themselves, made with corn and water, *fruge madida*. The manner of making this liquor is somewhat different in Gaul, Spain, and other countries, and it is called by many various names; but its nature and properties are every where the same. The people of Spain, in particular, brew this liquor so well, that it will keep good for a long time. So exquisite is the ingenuity of mankind in gratifying their vicious appetites, that they have thus invented a method to make water itself intoxicate." The manner in which the ancient Britons, and other Celtic nations, made their ale is thus described by Isidorus, (Orig. lib. xx. c. 2.) and Orosius, (lib. iv. p. 259.), cited by Henry (Hist. of England, vol. ii. p. 364, 8vo): "the grain is steeped in water, and made to germinate, by which its spirits are excited and set at liberty; it is then dried and ground; after which it is infused in a certain quantity of water; which, being fermented, becomes a pleasant, warming, strengthening, and intoxicating liquor." This ale was most commonly made of barley, but sometimes of wheat, oats, and millet. Geopon. lib. vii. c. 34. p. 203. This liquor is of such antiquity in England, that we find mention of it in the laws of Ina, king of Wessex. Ale was the favourite liquor of the Anglo-Saxons and Danes, as it had been of their ancestors, the Germans. Tacitus, de Mor. Germ. c. 23. Before their conversion to Christianity, they believed that drinking large and frequent draughts of ale was one of the chief felicities which those heroes enjoyed who were admitted into the hall of Odin. Amongst the liquors provided for a royal banquet, in the reign of Edward the Confessor,

ale is particularly specified. In Scotland and Wales they had two kinds of ale, called common ale and spiced ale; and their value was thus ascertained by law: "if a farmer hath no mead, he shall pay two casks of spiced ale, or four casks of common ale, for one cask of mead." By this law, a cask of spiced ale, nine palms long, and 18 palms in diameter, was valued at a sum of money equal in effect to 7*l.* 10*s.* of our present money; and a cask of common ale, of the same dimensions, at a sum equal to 3*l.* 15*s.* Hence it appears, that common ale was at this period an article of luxury among the Welsh, and that it could only be obtained by the great and opulent. Wine at this time seems to have been unknown even to the kings of Wales, as it is not mentioned in their laws; though Giraldus Cambrensis, who flourished a century after the conquest, informs us, that there was a vineyard in his time at Maenrper, near Pembroke, in South-Wales. Henry's Hist. vol. iv. p. 393. By a statute of 3; Henry III. in 1272, mentioned by Hume (Hist. Eng. vol. ii. p. 224.), a brewer was allowed to sell two gallons of ale for a penny in cities, and three or four gallons for the same price in the country. But the first assize of ale was fixed by the famous Stat. 51 Henry II.

The following method for preserving ale from turner for use in long voyages, was first published by Dr. Stubb's (Phil. Trans. No. 7.), and experience has evinced its utility. To every malet of five gallons, after being placed in a cask on ship-board not to be stirred any more, put in two new laid eggs whole, and let them lie in it. In a fortnight, or a little more, the egg-shells will be entirely dissolved, and the eggs become like wind-eggs enclosed only in a thin skin; after this the white is preyed on, but the yolks are not touched or corrupted; and by these means the ale has been so well preserved, that it was found better in Jamaica than at Deal.

The duties on ale and beer make a considerable branch of the revenue in England. They were first imposed in 1643, when the excise was first established, again by Car. II. and have been continued by several subsequent acts of parliament. By 43 Geo. III. c. 67, for every barrel of beer or ale, above 16 shillings a barrel, (exclusive of the duty hereby imposed, and not being two-penny ale, nor table-beer, (the brewer shall pay ten shillings; and for every barrel of table beer, or beer or ale of 16*s.* the barrel, or under (exclusive of the duty), two shillings; and for every barrel of two-penny ale, (described in the seventh article of the Union with Scotland) four shillings and two-pence. The allowance for waste shall be three gallons out of 35 gallons, which shall be reckoned a barrel of beer or ale made by common brewers.

The saccharine matter extracted from the farinaceous seeds, of which ales are made, and subjected to a fermentation analogous to that of wine, imparts to our ales a quantity of alcohol; and they have, therefore, in general, the cordial, exhilarating, intoxicating, and sedative qualities of wine. But their effect, in these respects, depends partly upon the quantity and condition of the saccharine matter that is employed, and partly upon the management of the fermentation to which they are subjected. Barley is chiefly employed for the purpose of making ales, though it might be prepared from any of the cerealia; and this selection is very properly made, because its germination is most easily

conducted, and under its germination it gives out its sugar most readily, and in greatest quantity. Ales, made in the ordinary manner, will be stronger or weaker according to the quantity of the saccharine matter that is used; and this will be greater or less according to the quantity of well-ripened farina in the barley that is employed, according to the mode in which it is malted, according to the proper and complete extraction of the saccharine matter by water, and according to the dissipation in a greater or less degree, of a quantity of the superfluous water. The other qualities of ales, besides their strength or weakness, will depend upon the conduct of the fermentation. As the infusion of malt or wort is not so well disposed to fermentation as the juices of fruits, it will require the addition of a ferment; and afterwards the conduct of the fermentation will be very much the same with that of wines; at first very active, and then

slowly protracted for a long time: but, however ale is managed, its fermentation is not so capable of being rendered so complete and perfect as that of wine. In most ales there is probably a large portion of unassimilated farinaceous matter, which of course renders ales more nourishing than wines, and they are, *ceteris paribus*, more liable to acescency in the stomach than wines. It has been commonly supposed, that the viscidness of worts is never entirely corrected by the fermentation; and therefore that ales are more apt than wines to fill the vessels of the human body with viscid fluids; but Dr. Cullen thinks that this circumstance deserves little attention, as it is probable that the power of the gastric fluid, and of the fermentation which happens in the stomach and intestines, reduces the whole nearly to an equality in respect of fluidity. Cullen's Mat. Med. vol. i. p. 418, &c.

Alkali

ALKALI is the generic term for an order of salts of the highest importance, and the most familiar use in chemistry.

Alkali is a word of Arabian origin, and it was employed by the Arabian chemists and physicians, to express the salt which was procured from the ashes left after the combustion of several vegetables, particularly the salt *kali* of the desert, and several plants growing on the sea shore. The same salt is also found native in immense quantities, mixed with sea salt, in the waters and on the shores of several lakes of Lower Egypt, and has been known from time immemorial by

the name of *natron*, or the *nitre* of the ancients. The Greeks and Romans were equally familiar with the alkaline salt contained in vegetable ashes, which was termed *lixiviary ashes* (*lixivius cinis*, Plin.), whence the name of *alkaline ley*, *lixivium*, or *lixiviary salt*, which is still retained. The use of the word *alkali* was at first confined to the salt which was yielded by the *fixed* or incombustible ashes of vegetables; but the *volatile* salt, which rises in distillation of vegetable, and especially of animal matter, having been found to possess similar chemical properties with the fixed *lixiviary salt*, in the most essential

sential particulars, the respective appellations of *fixed* and *volatile alkali* have long been adopted by chemists. For the account of the process of procuring these salts as an article of commerce, for their natural history, and other particulars, we shall refer the reader to the words POTASH, SODA, and AMMONIA.

The properties common to all alkalies are the following: they have a highly acrid taste, which acts with so much energy upon the tongue as to produce the sensation of burning, and unless they are much diluted, they very soon corrode the thin skin which covers it, and produce a small eschar or dead part, which, for a time, leaves a slight sore on that sensible organ. They have an unctuous feel to the finger, not from any oily nature in the alkalies, but because they directly dissolve the surface of the skin, and produce a kind of soap. They effect a remarkable change on several vegetable colours. The red of roses, and the blue of violets, are turned by them to a dull green; the red of archill or litmus, to a blue; the yellow of turmeric, the light brown of jalap root, liquorice root, and of many other roots and woods, are all rendered much deeper in colour, approaching to a brick-red. They unite with sulphur, forming compounds which have the property of absorbing the oxygen from atmospheric air, and, when moistened, of giving out a peculiar fetid gas. These compounds have been denominated *alkaline hepars*, or *livers*, and in the modern nomenclature, *sulphurets*. They have a very powerful action on almost all vegetable and animal matters, producing speedy disorganization, and dissolving them into a thick pulp. With oils they form the well-known compound, *soap*. They are largely soluble in water, giving out heat on union with this liquid. They unite with every acid, and produce *neutral salts* of various degrees of solubility; in which, when the contents are mutually saturated, the distinguishing properties of both acid and alkali are neutralized, and no longer to be perceived. Owing to the very strong affinity which they bear for acids, they decompose the acid solutions of all metals and most earths. These are the most characteristic properties common to *all* alkalies; but there are others which are confined to *one* or other of the two species. These we shall enumerate, referring the reader for more particular information, to the individual articles.

The VOLATILE ALKALI (*Ammonia*) is distinguished, (as its name implies) by its volatility. The purest form in which it is known to us is that of a gas, which is permanent at any degree of cold that has ever been applied to it, and unites readily with water in large quantity, from which, however, it may be again expelled by a heat much below boiling. It has never been procured in a solid form, unless combined with some other substance; nor as a liquid, except by its union with water. It differs remarkably from the fixed alkalies in having a very pungent smell, which highly stimulates the nostrils, and excites coughing and tears. Owing to the ease with which it assumes a gaseous form, it is incapable of uniting with many substances which the fixed alkalies will dissolve, when assisted by fusion in a strong heat. The volatile alkali is weaker in all its affinities than the fixed. It is also the only one which is decidedly proved to be a compound substance; the nature of its constituent parts (which are hydrogen and azote) having been ascertained by numerous experiments both of synthesis and analysis. See AMMONIA.

The FIXED ALKALIES, (*Alkali fuerbeständige*, *Laugen-salz*, Germ.-*Alkali fissa* Ital.) are the proper *lixivatory* alkalies, or those that are procured by lixiviation of the ashes of burnt vegetables. They may be obtained in a very pure solid form, either crystallized, or as a simple concrete. Besides the properties which have been mentioned as common to all

alkalies, these possess considerable fixity in fire, and at a red heat they run into thin fusion. A higher heat, however, volatilizes them, and they fly off in sensible vapour. The fixed alkalies, when in fusion, will readily dissolve siliceous earth into the perfectly homogeneous transparent compound, GLASS. They also will dissolve by heat all the metallic oxyds, and thereby receive various tints. They assist in the fusion of all earthy and metallic admixtures, and their degree of fixity in the fire enables them to combine more intimately than the volatile alkali, with sulphur, phosphorus and charcoal. When pure and solid, they are remarkably deliquescent, absorbing water from every surrounding medium; and hence they have been used by chemists to render the air of any vessel in which they are confined, perfectly dry. The fixed alkalies are two in number, POTASH and SODA, the former being procured from the ashes of all vegetables except marine plants, and a few that grow near the sea shore, which yield the latter alkali. The former is also termed the *vegetable* alkali, and the latter, (owing to its being sometimes found native in the earth), is called the *mineral* alkali. The general properties of these two alkalies were long known, and they were long employed in various arts, before the circumstances by which they are distinguished were well ascertained, and their separate existence established. The close resemblance which they bear to each other when pure, and the similarity in all their most remarkable chemical properties, prevented a proper distinction between them; and it was chiefly by the researches of Pott, Duhamel and Margraaf, that the nature of the two alkalies was fully explained. The two neutral salts with which the older chemists were the most familiar, nitre and sea-salt, have for their bases, the former the vegetable, and the latter the mineral alkali; and it was principally by enquiries into the properties and decomposition of these neutral salts that the distinct nature of their alkaline bases was decided.

Potash and soda differ from each other in the strength of their affinity with acids, which is greater in the former; in some slight variation in their action on oils and animal fats; but chiefly in the neutral salts which they form with the acids, which in all cases differ in form of crystallization, in solubility, often in taste, and in several other particulars.

The intimate nature of the fixed alkalies is still unknown to us. From the very strong analogy with the volatile alkali, the component parts of which are fully established, it must be considered as highly probable that the fixed alkalies are compounds, though their decomposition has not yet been effected by any experiments which can be allowed to be unexceptionable. Fixed alkalies have been supposed to be generated by the process of combustion of vegetables; since no plants, even those whose ashes yield the most of this salt, contain before combustion any sensible quantity of uncombined alkali. The accurate analyses of several of the modern chemists have however detected, in the native juices of plants, several neutral salts, whose alkaline bases are united to an acid which is easily destructible by fire. But for this, and other speculations on the nature of the fixed alkalies, we shall refer the reader to the article POTASH.

ALKALI (*Cautic* or *Pure*). The alkaline salt procured from vegetable ashes, besides being mixed with other salts, and with earth, is always saturated more or less completely with fixed air, or *carbonic acid*; so that the fixed alkali which was the subject of the experiments of all the chemists, till within a few years, was a salt compounded of carbonic acid and the alkaline basis. The beautiful experiments of Dr. Black fully illustrated this point, and shewed, that the reason of the greatly increased causticity of alkalies, when mixed with quick-lime, was the loss of the carbonic acid, which had passed from the alkali to the earth. *Cautic* alkalies, there-

fore, are alkalies deprived of carbonic acid by quick-lime or any other method; and this is the only state in which, properly speaking, alkalies can be considered as *pure*; though even when they contain much of this volatile acid, the peculiar qualities of the alkaline part predominate so considerably as to enable them to exhibit (though in a weaker degree) all the chemical properties by which alkalies are characterized.

ALKALI (*Effervescent or Mild*), is opposed to the state of causticity, and expresses that degree of saturation with carbonic acid, which, as has just been mentioned, diminishes, but does not suppress, the characteristic properties of the alkali. Owing to the alkali obtained from vegetable ashes being always left after combustion in union with carbonic acid, *effervescence with acids* was considered by the older chemists as an essential character of alkalies in general, who thus ascribed to a property inherent in this genus of salts, an appearance which is now known to depend upon the expulsion of the gaseous acid. The terms *caustic* or *pure*, and *effervescent* or *mild*, are applied to the volatile as well as to the fixed alkalies.

ALKALI (*Extemporaneous*), is a mild vegetable alkali, prepared by deslagrating nitre with tartar. See CARBONAT OF POTASH.

ALKALI (*Fluor*), is a solution of pure AMMONIA in water.

ALKALI (*Phlogistic*), is prepared by calcining carbonated potash with bullocks' blood or other animal matter, in which process it unites with the PRUSSIC acid, formed during the calcination.

ALKALI (*of Tartar*), or *Salt of Tartar*, is properly a mild vegetable fixed alkali, prepared by the combustion of tartar, which yields it in great purity. The name is used more extensively for any pure carbonated potash, and it is the term by which this salt is more generally known in common language and in medicine.

ALKALINE EARTHS. It is by no means easy to draw the line accurately between alkalies and earths. The original idea of an EARTH, entertained by the ancient chemists, was that of a substance of considerable density, insoluble in water, without taste, smell, or any perceptible action on the organs of sense, entirely unfusible, and fixed in the most intense fire; and, in short, with properties as opposite as possible to those of a SALT. This opinion principally attached to earth, considered as one of the four elements of which the material world was supposed to be constituted. The progress of chemical investigation having, however, discovered several species of earths, which could not by any means be proved to be compounds, in which the simple or universal earth was so disguised as to lose some of its essential characters, it became necessary to alter and modify the original definition of an earth, and to allow to it more of a saline nature.

Some of the modern chemists, therefore, have adopted the term *salifiable*, and others *alkaline* earths, in order to allow of more accuracy in systematical arrangement. By *alkaline* earth has been meant an earth which agrees with alkali in the property of solubility in water to a certain extent, and thereby rendering it rapid, of changing to green certain blue and red vegetable colours; of absorbing carbonic acid with eagerness, and of possessing, when pure, those *caustic* or *acid* qualities that so much distinguish the alkalies. *Magnesia*, *lime*, *barytes* and *strontian*, are the earths which may be termed *alkaline*, but the former is very imperfectly so, being scarcely more soluble in water than flint; and though its habitudes with carbonic acid are partly similar to those of the alkalies, it does not acquire any taste, or any degree of causticity, by the loss of this gaseous acid. *Barytes* and *strontian*, on the other hand, approach nearer to an alkaline

nature than lime, in being very largely soluble in water, and readily crystallizable from its solution in a determinate form. They have therefore been actually enumerated as alkalies by Fourcroy, who reckons the following; *potash*, *soda*, *ammonia*, *barytes*, and *strontian*. The two latter even stand before the three ancient alkalies in their order of affinity with most acids, but, till the intimate nature of the fixed alkalies be fully cleared up, it will perhaps be proper to restrict the term *alkali* to the three above-mentioned, and to retain in the class of *alkaline earths* magnesia, lime, barytes, and strontian, all of which, however they may be alkalies in many respects, differ from them in being unfusible *per se* in very intense fire, and being entirely incapable of being volatilized by the utmost heat that has ever been applied to them.

ALKALI, in *Botany*. See SALICORNIA.

ALKALINE, in a general sense, something that has the properties of an ALKALI.

In this sense we say, alkaline salts, alkaline spirits, alkaline substances, &c.

Alkaline salts, considered in their reference to the *Materia Medica*, are known to possess antiseptic powers. Experiments upon them, out of the body, sufficiently indicate and attest these powers; but Dr. Cullen observes, that it is at the same time equally well known, that they are constantly imbued with such an acrimony, that they cannot by themselves be introduced into the body without acting more by their stimulant than by their antiseptic powers. The volatile alkali may sometimes be an useful remedy in putrid fevers; but it cannot, as some have imagined, be given more freely on account of its antiseptic powers, as it can never be given copiously enough to have any effect by these qualities. The volatile alkaline salts shew their stimulant power in every dose, wherever the energy of the brain is weakened, and consequently the action of the heart is languid, or requires to be accelerated. In such cases this stimulus is among the safest, as it is always transitory; and when their acrimony can be covered, so as to pass the mouth and fauces without irritation there, they may be given in large doses from 10 to 20 grains. These are prepared in two different ways; one of which is from sal ammoniac, which gives the ammonia of the London Dispensatory, or the sal ammoniacus volatilis, and spiritus salis ammoniaci of the Edinburgh. These are the purest forms of the volatile alkali, the most free from any adhering animal substances; but whilst the process of preparing a volatile alkali from the bones or other solid parts of animals continues, there will come into the shops a salt and spirit that can hardly ever be so pure, from some empyreumatic animal substance adhering to it; and such an adherence may probably give some peculiar quality to the salt and spirit, and render it more antispasmodic. It cannot be very considerable in any doses of the salt or spirits given to adults, but it may produce more sensible effect in the spasmodic affections of infants. The liquid volatile alkali is commonly employed in its mild state; but by a distillation of the sal ammoniac with quick-lime, the alkali may be obtained in its caustic state. In this state it may be readily joined with spirit of wine, and gives the spiritus salis ammoniaci of the Edinburgh Dispensatory, or the spiritus salis ammoniaci vinosus of that of London. The combination affords an excellent menstruum for dissolving the several fetid substances employed as antispasmodics, and renders them more suddenly diffusible, and perhaps gives them a greater effect in all spasmodic affections. The caustic volatile alkali is seldom administered alone; but if its acrimony be covered while it passes the mouth and fauces, it may be very safely employed. Its chief use is external, and when smelled at the nose, it gives a more powerful stimulus than the mild alkali can do. Its acrimony is so considerable, that when applied to the skin, it

readily irritates, and even inflames it, and may be so managed, as to prove an useful stimulant and rubefacient in many cases. But this requires its being blended with a mild, expressed oil, so as to prevent its inflaming too much. See *Volatile Oil*. The fixed alkaline salts have been commonly administered as diuretics. Dr. Cullen has chiefly employed the vegetable fixed alkali, and has sometimes obtained its effects in a remarkable degree; but he has been often disappointed, which he ascribes to the neutralization of the alkali in the stomach, and in that state they could have no other effect than other neutrals, which is commonly inconsiderable, either as laxatives or diuretics. Alkalines do, however, occasionally manifest their diuretic power: and upon the supposition of their neutral state in the stomach, their considerable operation as diuretics cannot be easily accounted for. Of this fact Dr. Cullen offers two explanations. One is, that the quantity of alkali thrown into the stomach may be more than the acid can there neutralize, and therefore some portion of it may reach the kidneys in its alkaline state, and prove a more powerful stimulant than any neutral salt would be; and on this ground a large quantity of alkali is always necessary to produce diuretic effects. Another explanation of the fact is as follows. As the acid of the stomach may be presumed to be of the nature of the fermented acid of vegetables, so an alkali joined with it must form a regenerated tartar, a sal diureticus, or kali acetatum; and if this be less purgative, and more diuretic than other neutrals, while it is also conveyed to the blood-vessels in larger quantity, we can understand why, from these circumstances, the fixed alkali may often appear diuretic. With respect to its operation as a diuretic, another conjecture may be offered. When it is given with bitters, after the manner of Sir John Pringle, it commonly proves diuretic; and Dr. Cullen imagined, that as the bitters are absorbents of acid, they might absorb so much of that present in the stomach, as to prevent its being so fully applied to the alkali. As alkalines may be often prevented, by purging, from reaching the kidneys, so their diuretic effect may be of-

ten more certainly secured by giving an opiate at the same time; and for the utility of this practice, see Dr. Mead on the subject of Dropsy. Besides the laxative and diuretic powers of the fixed alkali, another is ascribed to it, which is that of dissolving the fluids, or the concretions which may happen to be formed in them, expressed by French writers under the denomination of *fondant*. Dr. Cullen does not allow it to possess this power to any great degree, or to produce the effects in this way that have been ascribed to it. Cullen's *Mat. Med.* vol. i. p. 568. Vol. ii. p. 382. 512.

ALKALINE *acrimony*, in *Medicine*, signifies a morbid quality in the blood, which is indicated by a desire of and thirst after four things, loss of appetite, and aversion to alkalescent food, nidorous eructations, putrid ulcers on the lips, tongue, and other parts in the mouth, sickness in the stomach, a frequent *dysarrhea*, a sense of heat, lassitude, and general uneasiness, a dissolution of the texture of the blood, the urine high-coloured and red. It produces a putrescency in the blood, &c. and is to be remedied by the same means as the sea-scurvy and other putrid disorders.

ALKALIZATION, ALKALIZATIO, in *Chemistry*, the act of impregnating a liquor with an *alkaline* salt.

This is done either to make it a better dissolvent, for some particular purposes; or to load the phlegm, so as it may not rise in distillation, whereby the spirituous parts may go over more pure.

ALKALIZATION, is a name applied to operations, by which alkaline properties are communicated to bodies; or to those by which alkali is extracted from bodies which contain it, or in which it may be formed; e. g. *spirit of wine* is said to be alkalized, when it has been digested upon alkali; a part of which it dissolves, and thence acquires alkaline properties. On the other hand, when a neutral salt is decomposed in order to obtain its *alkaline* basis, this salt is to be alkalized. Vegetable substances, when reduced to ashes, may also be said to be alkalized, because the ashes contain fixed alkali.

Alum

ALUM, *ores of*, in *Mineralogy*. Under this head we include all those minerals which either contain alum ready formed, or are capable of yielding this salt by the process of manufacture. They may be conveniently divided into three families. 1. The saline, all the species of which are almost wholly soluble in water; 2. The earthy-saline, in which the soluble particles are diffused through a large proportion of earth; 3. The earthy, which containing no alum but only the materials of it, are insoluble and destitute of that sweetish astringent taste, which is characteristic of the two former.

1. Family—SALINE. Taste aluminous, almost wholly soluble in water.

Species 1. Capillary alum.—*Vitriolum halotrichum*, Werner.—*Haarfaltz*, Germ.—*Termes timfo*, Hung.

The colour of capillary alum is either pure or yellowish white, passing into isabella yellow and grey, upon exposure to the air. It occurs in long very tender capillary crystals

accumulated on an earthy base, or amorphous or tooth-shaped. Its external lustre is glassy and generally glimmering, advancing sometimes to the little-shining, in the pure white varieties approaching more or less to the mother of pearl lustre; internally it is shining or little-shining with a glassy lustre. The amorphous has a fine, straight or curved fibrous fracture. It flies, when broken, into indeterminate not particularly sharp fragments. It appears sometimes to contain slender columnar distinct concretions: is transparent, soft, and very brittle; though each separate crystal has a slight elasticity: sp. grav. according to Scopoli 1.835: has a sweetish astringent taste.

By the analysis of Scopoli, it is soluble in three times its weight of water, and consists of alum and sulphated iron. It is met with at Cremona and Chemnitz in Hungary, also in the quick-silver mines of Ydria, where it has generally been mistaken for white vitriol.

Species 2. Plume alum.—*Alumen nativum* f. *plumosum*, Werner.—*Natürlicher* f. *feder alun*, Germ. *Fjüdar alun*, Swed.—*Fiaeragtig alun*, Dan. *Alun de plume*, Fr.

The colour of this substance is yellowish or greyish white. Its external lustre is dull, but sometimes glimmering, or even little-shining. It consists of slender irregular hair-shaped fibres, either single or accumulated, and slightly adherent to each other; is seldom stalaclitic or amorphous. It is usually opaque, but sometimes also transparent or semitransparent. It excites the same taste on the tongue as the preceding species.

It is found efflorescing on bituminous schistus at Göttwig in Austria, on grey argillite in Carinthia, in clefts and caverns on Stromboli, the Solfatara, the grotto of St. Germano, Miseno, and other places in Italy.

In Klaproth's Essays is an analysis of the native alum of Miseno, from which it appears, that 100 parts yield by simple solution and crystallization 47 of perfect alum, and 29 more by the addition of the necessary quantity of potash, the remainder being sand with a little selenite, and a small trace of oxydated iron.

Species 3. Mountain butter.—*Vitriolum alumen butyraceum*, Werner.—*Bergbutter*, Germ.

Its colour is of a more or less dun isabella yellow, or yellowish brown. It occurs amorphous commonly overlaying the surface of aluminous schistus in lumps or clots. Internally it is shining, with a waxy lustre. At first it is very soft, but by exposure to the air it becomes of a middle consistence, between crumbly and compacted, and is then of a strait shivery fracture. Its fragments are indeterminate, blunt. Its distinct concretions are small and fine granular. It is transparent on the edges, and slightly elastic; feels somewhat unctuous, and leaves on the tongue an acerbly sweetish astringent taste.

It occurs in many places where the aluminous schistus is plentiful, and exposed to the air, as at Muskaw in the Oberlausitz: is also found in Siberia.

It has not yet been analysed, but probably differs from the preceding, in containing a larger proportion of clay and iron ochre.

II. Family. EARTHY-SALINE. Taste aluminous, very little soluble in water. All the ores that belong to the third family are occasionally found to have undergone a natural change, similar to what is produced in them by art at the alum manufactories; in consequence of which they often yield, by lixiviation, a variable proportion of alum, and exhibit the sweetish astringent taste peculiar to this salt. 1. Upon the purely sulphureous ores or alum-stone with its varieties, this alteration seems to take place by the action of subterranean fire: alum is also probably formed in mere earthy compounds of silice and alumine, that contain no sulphur when they overlie heated sulphureous strata, by which they are first cracked and then penetrated with sulphureous acid vapours. Examples of both these occur in Italy at La Tolfa, not far from Civita Vecchia, and the Solfatara in the Neapolitan dominions; from 100 parts of which Bergman obtained by mere lixiviation eight parts of perfect alum. 2. The well known property of pyritous and pyrito-bituminous matters to heat, and afford vitriolic salts by the combined action of air and moisture, may also be traced, though in a slighter degree, in the aluminous ores of this description; hence it is that the upper strata of the softer aluminous schistus, of the alum earth, and the sulphureous peats are occasionally impregnated with alum. The marshy black soil of Arragon, that yields pure alum by lixiviation (Bowles's Spain, p. 388.), appears to be of this kind; also the aluminous turf of Helsingborg in Scania

(Bergm. Ess. vol. i. 353.); and a vein of black earth in the Shetland islands, containing alum and sulphated iron. Alum is also extracted from fossil wood in Hesse, (Vogel. p. 322.) Springs in the neighbourhood of these strata sometimes hold a little alum in solution, as those near Halle (Chym. Ann. 1788. p. 224.)

Family III. EARTHY—no aluminous taste—not soluble in water.

Species 4. Alum-stone. *Argilla aluminaris* Tolfensis, Wern. *Alumen lapid. calcar. mineralizat.* Wall.—*Alaunstein*, *alaunkalchstein*, Germ.—*Alunsten*, Swed. *Alunrig steenleer*, Dan.—*Pierre alumineuse de la Tolfa*. *Pierre calcinaire alumineuse*, Fr.—*Pietra calcinosa aluminosa*, Ital.

Alum-stone is greyish or yellowish white, isabella yellow, or light smoky grey; amorphous. Its internal lustre is dull, seldom glimmering. Its fracture uneven, splintery. Fragments indeterminately sharp-cornered. It has distinct conchoidal concretions, which might be mistaken for a fine schistose texture. Is slightly transparent at the edges. Is half-hard passing into hard. Brittle, insipid, feels meagre; and adheres slightly to the tongue.

Its sp. grav. according to Kirwan, is 2.424. It has an earthy smell, and when projected on a red hot iron it hisses and gives out a black smoke, a slight sulphureous smell, and the residue acquires a reddish colour. According to Monnet's analysis, it consists of sulphur and clay, in nearly equal proportions, together with a little iron and potash. Bergman found it to contain about 43 sulphur and inflammable matter, 35 alumine, and 22 silice.

It is found in masses and veins running through argillaceous rocks at La Tolfa, in the states of the church, and in the ore from which the Roman alum is prepared. A volcanic origin has been generally attributed to it, but apparently without reason, as the veins of La Tolfa have been traced into the Apennines. It was formerly supposed to be mostly calcareous, as is evident from the synonyms quoted above. La Metherie (Theorie de la Terre, vol. ii. p. 215.) has hazarded an opinion that it is principally alum supersaturated with alumine, and therefore earthy and insoluble. This is a notion which derives high probability from the recent analysis of this ore, by Vauquelin (An. de Chem. vol. xxii. p. 275.) who obtained from it

Alumine	-	43.92
Sulphuric acid	-	25.
Potash	-	3.08
Water	-	4.
Silice	-	24.
		100.00

A similar kind of ore has been discovered in rocks near Poliniere in Brittany.

Species 5. Alum-slate. *Aluminous schistus*, *alaunschiefer*, Germ.—*Alun steifer*, Swed.—*Ardoise alumineuse*, Fr.—*Lavagna aluminosa*, Ital.—*Tímso pala*, Hung. *Kwaffzowoi schiefer*, Russ.

Of this there are two varieties.

Var. 1. Common alum-slate. *Gemeiner alaunschiefer*, Germ.—*Argilla aluminaris schistosa vulgaris*, Werner.

Its colour is bluish black, sometimes greyish black. Amorphous, or in concentric balls imbedded in the strata. Its internal lustre is glimmering, or dull. Fracture strait or curved flaty. It flies when broken into broad shivers, or trapezoidal fragments. Gives a grey streak; feels rather smooth but meagre. Is soft, brittle, and but little elastic.

Var. 2. Shining alum-slate. *Glanzender alaunschiefer*, Germ.—*Argilla aluminaris schistosa nitida*, Werner.

It is of a bluish black colour, generally passing into the iron black—occurs amorphous, in large strata. The lustre of its parallel fracture is shining or even brightly shining, with a lustre between common and semi-metallic: that of its cross fracture is dull, or at most glimmering. Fracture thick and curved slaty, seldom thin slaty. Its fragments therefore are sometimes thick and sometimes thin shivery. It feels smooth; is half hard; brittle; and but little elastic.

Both varieties are found in Norway, at Whitby in England, in Sweden, in Saxony, and various other provinces in Germany. The alum of Great Britain and the north of Europe is almost entirely made of it, for which use the second variety is said to be the best adapted. It commonly occurs in the neighbourhood of coal, and seems to differ in no respect from the bituminous shale impregnated with pyrites.

Species 6. Alum-earth — *Pyriticous clay, alun erde* Germ.—*Argilla aluminaris bituminosa*, Werner. *Alunjard*, Sweed.—*Terre alumineuse*, Fr.—*Timsös feld*, Hung.

It has a light or dark blackish brown, brownish black, or blackish grey colour. Occurs in large strata of earthy or irregularly slaty masses. It is generally dull, but when containing scattered particles of mica, becomes occasionally glimmering. Its fracture is between compact earthy and imperfectly slaty. Its fragments are partly flaky and partly irregularly blunt cornered. Its streak has a feeble lustre. It is very soft, and may be rubbed to powder between the fingers; is brittle, and of very little elasticity.

When placed among burning coals, it generally blazes a little; and when moistened and exposed to the air in large quantities, it heats and not unfrequently inflames. From 100 parts of it, after torrefaction, Klaproth obtained 10 alum, 7.25 sulphated iron, 2.25 sulphated lime, and 1 sulphated magnesia.

It is found in alluvial and secondary strata, and is intimately connected with bituminous wood, alum slate, and coal shale. Is used in the manufacture of alum in Germany.

Lenz, Versuch der Mineralien.—Widenman, handbuch der Mineralogie.—Lametherie, Theorie de la terre.—Bergman's Essays—Klaproth's analytical Essays.—Kirwan's Mineralogy.

ALUM, *Manufacture of.*

In order to appreciate rightly the peculiar advantages or disadvantages of the several methods of manufacturing this salt, it will be necessary to enter into a previous enquiry concerning the nature and proportions of its elements, and the different chemical varieties of alum, which have hitherto been confounded under the same name.

§ 1. *Analysis and Composition of Alum.*

The identity of the earthy base of alum with pure clay, was first ascertained by Geoffroy and Hellot, and the successive experiments of Pott, Margraaf, and Macquer, upon the same subject, put an end to the controversy concerning the nature of aluminous earth, which has ever since been universally received as the same with pure clay or alumine, according to the reformed nomenclature. The acid in alum has always been considered as the sulphuric, and the only question among chemists on this head is whether the acid is necessarily in excess. A solution of alum reddens litmus paper, and exhibits other properties of an uncombined acid; but on the other hand it is contended by Morveau, that crystallization and edulcoration would effectually

separate any such excess, and therefore that the change of vegetable colours is not an unequivocal proof of superabundant acid. Reserving the consideration of this and similar cases till we come to treat of the article SATURATION, it is sufficient to observe here, as indeed Bergman has clearly shown, that the acid exists in alum with two very different degrees of affinity. By the action of iron filings on a solution of alum, all the signs of uncombined or loosely adhering acid are destroyed, sulphated iron is produced, and a white earthy precipitate takes place, consisting of the alum deprived of a small portion of its acid, but still retaining the greater part, as may be proved by the further decomposition of it by a caustic alkali; and to this superabundant or slightly combined acid, is entirely owing the taste, the solubility, and most of the other external characters of the salt.

The component parts of alum, according to Bergman, are 38 sulphuric acid, 18 alumine, and 44 water of crystallization. Observing, however, that those solutions, which contained a great excess of sulphuric acid could not be brought to crystallization by the addition of lime, soda or barytes; but only by means of potash or ammonia; finding also sulphat of potash in many species of alum, he appears often induced to believe that the alum of commerce is a triple salt consisting of sulphuric acid, alumine and potash. The subject remained in this state of uncertainty till it came under the notice of the most eminent analyst of modern times, the accurate and indefatigable Vauquelin, to whose admirable Memoir on the combinations of alumine with sulphuric acid, we are indebted for the final illustration of a question of equal importance to the chemist and manufacturer.

In order to ascertain the component parts of alum, and to determine the necessity and peculiar agency of alkalies in its preparation, he dissolved in pure sulphuric acid some alumine equally pure; the solution was evaporated several times to dryness to drive off the excess of acid, and the dry and pulverulent residue being then re-dissolved in water, was brought by evaporation to various states of specific gravity for the purpose of crystallization; but, notwithstanding every precaution, a soft magma, consisting of crystalline flakes, was all that could be procured. The solution, which had thus constantly refused of itself to afford crystallized alum, began to deposit some immediately on the addition of a few drops of potash, and by gradually adding the alkali, drop by drop as the deposition of alum ceased, the whole was converted into pure alum, without the smallest mixture of sulphated potash.

Another portion of the same pure aluminous sulphat was mixed with carbonated soda, but without obtaining any crystals. Nor were lime or barytes more efficacious.

Hence it appears plainly that the use of potash is not merely to engage the excess of acid, otherwise soda, barytes and lime, ought to have produced the same effect. Again, if potash and ammonia unite only to the superabundant acid, the sulphats of potash and ammonia should occasion no change in the pure aluminous sulphat; but, on the contrary, if they form an essential constituent part of alum, then they should produce the same effects when combined with sulphuric acid, as when pure. To ascertain this, a solution of sulphated alumine was mixed with a few drops of sulphat of potash, the immediate effect of which was the production of octahedral crystals of alum. Sulphat of ammonia produced the same result.

It might still, perhaps, be objected that the action of these salts, as they are remarkably greedy of sulphuric acid, determined the crystallization of the alum, by the simple absorp-

tion of superfluous acid. In order to determine this, some uncrystallizable aluminous sulphat was mixed with acidulous sulphat of potash, and afforded as great an abundance of alum as when the neutral sulphat of potash was made use of. Hence, no doubt can remain concerning the influence and particular mode of action exercised by potash and ammonia in the manufacture of alum.

The experiments of Bergman and of several other chemists ascertained, that when a solution of common alum is boiled with a quantity of pure alumine, this last combines with it, and forms a peculiar salt insoluble in water, known by the name of neutral aluminous sulphat, or alum saturated with its own earth. To this fact was added another of equal importance, by Vauquelin, namely, that the earthy salt thus precipitated retains its potash or ammonia, for by digestion in dilute sulphuric acid, it is dissolved, and affords octahedral crystals of alum; it even appears from the memoir of this philosopher quoted above, that the presence of one of the two alkalies is necessary to the formation of this neutralized alum. To an uncrystallizable solution of sulphated alumine perfectly free from alkali, he added some pure alumine, and found that a part of it was dissolved to the complete saturation of the acid, but that no precipitation took place; having then added a few drops of sulphat of potash, a precipitate was deposited shortly after, possessing all the properties of the foregoing saturated alum. Hence is established the necessity of sulphated potash or ammonia, to enable alum, by combining with a larger proportion of its base, to pass to the earthy state.

The alum of commerce always contains sulphat of potash either alone or mixed with sulphated ammonia, and as it is often of consequence to the manufacturer to know the absolute and relative proportions of these salts, the following method of analysis may be had recourse to. First, let a small piece of the alum be reduced to powder, and mingled with a solution of caustic potash in sufficient quantity to decompose it entirely: if then, upon gently heating, it gives out an ammoniacal odour, as is generally the case, this indicates the presence of sulphated ammonia. Having obtained this indication, let two or three hundred grains of the alum be dissolved in distilled water and put into a tubulated retort, and then add quick-lime, equal in weight to the salt: by making this mixture boil for about twenty minutes, the whole of the ammonia will be expelled, and may be condensed by cold water in the receiver, or a Woulfe's apparatus: this ammoniacal liquor, being then carefully saturated with sulphuric acid and crystallized, will shew the quantity of sulphated ammonia. The residue in the retort being mixed with warm water and filtered, a clear liquor will be obtained, containing the sulphat of potash, with some celestine; this latter will be precipitated by boiling and evaporation, and the remaining fluid will then deposit the sulphat of potash in a crystalline form. When the previous assay does not indicate the presence of ammonia, the alum is to be decomposed by caustic ammonia, the precipitate is to be well washed, and the liquors being added together, are to be gently evaporated to dryness; the salt thus obtained is to be heated in a crucible till it ceases to exhale white vapours of ammoniacal sulphat, and the residue is sulphat of potash.

§ 2. *Manufacture of Alum from the saline-earthly ores.*

The only place where this kind of ore is found in sufficient abundance to be worth working, is at the Solfatara, a few miles from Naples. The Solfatara, called by the ancients *Forum Vulcani*, *Campi Leucogei*, is a small plain, at the top of a hill, covered with a white soil, and exhaling sulphureous

vapours which, during the night, emit a pale blue lambent light: the ground, even at the surface, is considerably warm, proceeding, no doubt, from subterranean fire. It has continued in nearly the same state from the age of Pliny to the present time, and is celebrated by this author in his *Natural History* (lib. xxxv. ch. 50.) for its sulphur, but not for its alum, as the Abbé Mazzeas affirms. On the contrary, by his omission of the *Campi Leucogei*, when mentioning the various places from which alum was then procured, it is plain that the establishment of the alum works of the Solfatara is of more recent origin. The white clayey soil of this plain, being constantly penetrated by sulphureous vapours, and the exhalations during the night being for the most part mixed with the dew, and thus returned upon the surface, cause it to be covered with a light saline efflorescence. This, together with the earth to which it adheres, is daily collected and distributed into leaden cauldrons, so as to fill about two-thirds of their capacity; water is then added, till it stands about three or four inches above the surface of the clay, and this, in a few hours, by the assistance of the natural heat of the ground in which the cauldrons are set almost up to the brim, extracts the alum dissolved through the clay, and deposits it in rough crystals on its surface. These crystals being taken out and washed in the mother liquor, are put with fresh water into other boilers, and again dissolved as before, by the natural heat of the ground; the solution is then run through a filter into large wooden coolers, and in a day or two affords a large quantity of pure colourless crystals. Hence it appears that the alum exists ready formed in the earth of the Solfatara, and the whole of the manufacturing part is reduced merely to lixiviation and purification. The proportion of salt must necessarily be very variable, those parts that are exposed to the rain, and that lie above the general level, will contain the least. A specimen that was analyzed by Bergman yielded eight per cent. of alum. The Abbé Mazzeas, from six pounds of the earth, procured, by lixiviation, two pounds and a half of crystals, or about 41 per cent. The alum itself has not yet been analyzed; it seems probable, however, that its alkaline part is entirely potash.

§ 3. *Manufacture of Alum from alum stone.*

It is at La Tolfa, not far from Civita Vecchia, in the Roman state, that the manufacture of alum from this species of ore is principally carried on. All the alum known in commerce by the name of Roman alum is thus prepared, as well as the Levant or Smyrna alum.

The ore of La Tolfa forms veins of considerable hardness, which are separated by means of blasting from the rest of the rock; the pieces thus obtained are brought to the calcining oven, which is merely a hole dug in a rising ground, four or five feet in diameter, and from five to six in depth, with a lateral gallery, communicating with the open air, and the bottom of the furnace. The bottom being covered with faggots of brush-wood, the pieces of ore are skilfully laid over them, so as to form a kind of hollow vault, between the interstices of which is an ample passage for the smoke. As soon as the fire is kindled and the flame begins to appear between the stones, a workman is at hand to regulate the combustion, that it may be neither too great nor too feeble; in the course of from three to five hours the smoke begins to decrease, and the fire burns brightly; this is allowed to go on till the smell of burning sulphur begins to be prevalent, which is a sign that the ore is sufficiently roasted. The fire is now raked out, and the stones are left to cool. The sign of this first process being well conducted, is, that

the ore has now acquired the sweetish astringent taste of alum.

The second process begins by piling the calcined stones in long beds, on a sloping floor, the lower side of which is terminated by a ditch of water, extending along its whole length; from this ditch the beds are frequently sprinkled, and the water draining from them returns again into the reservoir. In about a fortnight the stones begin to crack and break down, and are at length, in forty days, more or less, overspread with a reddish efflorescence, and reduced into a kind of paste. A leaden boiler is now half filled with water, and when hot, fresh portions of the prepared ore are continually stirred in till a solution of sufficient strength is procured; the liquor as yet turbid is drawn off into another boiler, where it is subjected to a very gentle evaporation, at the same time that it becomes clear by the deposition of its earth. Having arrived at the point of crystallization, it is transferred by means of a pipe into a square wooden vessel, eight feet high by five wide, so constructed as to be readily taken to pieces; after remaining here for a few days, the mother water is poured out, to be boiled again with fresh alum ore in the first cauldron, and the crystals, when dried, are ready for sale.

From this account of the process, by an eye-witness (the Abbé Mazeas), it would appear that no potash or ammonia is added to the lixivium; it follows, therefore, that one or both these alkalies must be found in the ore, and this is actually the case, according to the analysis, by Vauquelin, already quoted in the preceding article.

The nature of this ore has been long misunderstood, as well as the rationale of its manufacture, and the analyses of it undertaken by Bergman and Monnet have only served to perpetuate the error. Both these chemists found a large proportion of sulphur in it, while Vauquelin finds only sulphuric acid; this apparent contradiction, however, may easily be reconciled, by considering that the ore contains carbonaceous matter enough to blacken it, and to give out a light flame when powdered and spread on a hot iron; hence, if the analysis of Bergman and Monnet was begun by distillation in a close retort, as it probably was, the decomposition of the acid and production of sulphur is readily accounted for. Admitting then the proportions of this ore, as ascertained by Vauquelin, to be sufficiently correct, viz. alumine 43.92; sulphuric acid 25.; potash 3.08; water 4.; silice 24.; it ought to be considered as a native saturated alum, with excess of earth and deficiency of alkali, intimately mixed with silice and inflammable matter. The action of the fire in the roasting is to drive off the inflammable matter, and from the sweet aluminous taste which is thus communicated to the ore, notwithstanding the loss by volatilization of part of its sulphuric acid, it seems also to effect a separation between the alum and the excess of earth. The subsequent cracking and breaking down upon exposure to the air and moisture, is probably caused by the absorption of water of crystallization.

But though a considerable proportion of alum is thus obtained, without the addition of potash, it may be worth while to enquire whether a larger quantity might not be procured by a trifling additional expense. The alum of La Tolfa contains by Vauquelin's analysis

49. sulphat of alumine
7. sulphat of potash
44. water

100

And according to Kirwan, (on the proportion of real acid,

&c. 1799,) 100 parts sulphat of potash are composed of 54.8 potash and 45.2 sulphuric acid; and 100 parts alum of 63.75 alumine and 36.25 sulphuric acid. Therefore, the 25 parts sulphuric acid in the ore require 37.1 alumine and 4.5 potash. But the ore only contains at most 3.08 potash, so that no more than 16 parts of sulphuric acid will be converted into alum; the remaining 9. will be left in combination with alumine in the mother water; and this agrees with the observation of Mazeas, who speaks of an unctuous acid, efflorescent salt being left in the residue of the lixiviated ore. The 9 parts of acid that are thus lost, may, however, be converted into alum, by the addition of 1.42 potash, or about 3. sulphat of potash.

From these data the ore of La Tolfa ought to yield by the present method of working it 78.5 per cent. of crystallized alum; or by the addition of 3 per cent. sulphat of potash, 125 per cent. of crystallized alum. In this calculation, however, no allowance has been made for the sulphuric acid volatilized in the roasting, and that portion of the salt which cannot be extracted by lixiviation in the large way from the prepared ore; both these circumstances will, no doubt, diminish considerably the produce of alum, but the proportions must vary much according to the skill and attention of the manufacturer.

§ 4. Manufacture of Alum from the Pyritous ores.

All the European alum, except what is manufactured at Solfatara and La Tolfa, as described in the preceding sections, is prepared from the alum slate or alum earth, and these containing only the remote principles of this salt, a much more complicated process is required than where the alum exists ready formed in the ore.

The only necessary ingredients in the pyrito-aluminous ores are clay, and pyrites, or sulphuret of iron. Besides these, however, there is generally a variable proportion of bitumen, lime, and magnesia. The best alum is procured from the black micaceous species in which the pyrites is thoroughly disseminated through the mass in such small particles as to be indistinguishable from the rest. Such, however, as contains even large nodules of pyrites, is very capable of being manufactured, much of the Swedish ore being of this kind.

The first thing to be done is to dispose the pyrites to decompose into sulphat of iron, (green vitriol), and this at the manufacture of Flone, in the department of Ourte, in France, is brought about by simple exposure of the ore to the action of air and moisture; this ore, however, is of the very best kind, moderately soft, free from bitumen, and with the ingredients well mixed, and even with these advantages, the process requires three years. The more stony and bituminous kinds, such as those of England and Sweden, are subjected to a previous roasting. For this purpose a layer of billet wood or coals is placed on a floor of rammed clay, and set fire to; upon this are thrown by degrees moderately small pieces of unburnt ore, till a stratum is formed, about half a foot in thickness; these presently take fire, by their own bitumen, and are then covered with a stratum of nearly the same thickness of ore that has been already roasted and lixiviated; to this succeeds a layer of unburnt ore, and thus alternate layers, eight or nine in number, are gradually added, till the pile is completed. Care is taken by protecting it from heavy rains, and covering those parts exposed to the wind, to keep up the heat of a moderate equable degree till the bitumen being consumed, the fire goes out of itself. If the ore is now examined it will be found to be of a reddish colour, containing a small quantity of sulphated iron and

alumine, and in some of the Swedish manufactories is accordingly lixiviated without any further preparation. In the English and German alum-works, however, the roasted ore is watered lightly, and exposed for a greater or less time to the action of the air, by which the sulphur of the pyrites is more completely oxygenated, and in consequence a larger proportion of alum is obtained. In the manufactory of Flone, already mentioned, the singularly judicious practice is observed, of lightly roasting the ore *after* spontaneous efflorescence.

The acid being thus developed, and in part united to the alumine, the process of lixiviation takes place. For this purpose the ore is thrown into large reservoirs of stone or wood, furnished with a false bottom, to serve the purpose of a filter; water is then poured on, and remains for twenty-four hours or more, in which time it dissolves the greater part of the salts; this being let out by means of a cock fixed nearly level with the bottom of the reservoir, a fresh quantity of water is added, in order to exhaust the ore of all soluble matter. The second lixivium is weaker than the first, but is afterwards concentrated by being used instead of water for the first lixiviation of the next parcel of ore. The water with which the lixiviation is performed is cold, and it might seem at first to be an obvious improvement to make use of boiling water; the experiment has, however, been tried without the desired result, the increased strength of the lixivium not being adequate to the time and expence of fuel. Where the lixivium is kept in large reservoirs, exposed to the weather, much depends on the dryness of the season, a few heavy rains weakening the liquor to such a degree, as to add considerably to the cost of boiling down. In Sweden and the northern countries, various attempts have been made to concentrate the liquor by freezing, but the success has not answered expectation; for a saturated solution of alum congeals at nearly the same temperature with common water.

The process of boiling down succeeds to that of lixiviation, and is always performed in leaden boilers, copper being for the most part too dear a material, and iron being attended with the inconvenience of decomposing alum. The lixivium is mixed in the boiler with the mother-water of a preceding boiling, and this is done either by filling the boiler with a mixture of mother water and liquor, and supplying the loss by evaporation with fresh liquor, or by filling the boiler at first with liquor, and supplying the waste by the above mixture. The evaporation lasts from twenty-four to forty-eight hours, according to the proportion of mother-water. In Saxony, where the proportion of mother-water is large, and the lixivium is brought to a high degree of concentration, the boiling continues without interruption for eight days. At the end of these respective periods the specific gravity of the liquor is assayed by a leaden hydrometer, or, with greater exactness, by filling a bottle of known size with the liquor, and then, by weighing it, to ascertain the comparative specific gravity between it and water. This being done, an alkaline solution is added, and the first crystallization is brought about. In the Saxon manufactories, where the liquor is uncommonly concentrated, as soon as the evaporation is finished the contents of the boiler are let out into a reservoir, where they are strongly agitated for half an hour, during which time a certain proportion of soap-makers lees and putrefied urine is added; and the liquor being then let into another vat, the crystals of alum begin immediately to be deposited; at the end of a few days the mother-water is laded out, and the crystals are collected and washed. The method followed in the English works differs somewhat from the Saxon practice; in these when the li-

quor appears by the hydrometer to be sufficiently evaporated, the fire is withdrawn from the boiler, and a stream of impure alkaline lixivium, from kelp and soap-maker's ashes, is let into the liquor already in the boiler; at the same time the cock at the bottom of the boiler is turned, so as to allow the contents of it to flow into a reservoir, by which management the two liquors are speedily and effectually mixed. It remains in this reservoir for three hours, during which it deposits an earthy and ferruginous sediment by the action of the alkali, and becomes of a clearer colour; it is now transferred into another large vat, and has its specific gravity again taken, according to which a greater or less quantity of putrid urine is added to lower it to the proper standard; being then agitated briskly for a quarter of an hour it is left at rest, and in the course of five days the crystals are deposited. In some French and Swedish manufactories the liquor, after being boiled down, is merely agitated for some time without adding any alkali, and then passed into the crystallizing tub. The rough alum being washed in order to separate it from the green vitriol which is deposited along with it, is put into a small pan with a little water, and when dissolved and boiling hot, some bullocks blood, or other similar substance, is usually added for the purpose of clarification: when this is effected, the liquor is run into casks, where the crystals are deposited in large masses; after ten or twelve days the mother-water is poured out, and the salt, being then dried, is ready for sale. By keeping in mind the analysis and experiments in § 1. of this article, it is easy to understand the *rationale* of the manufacture, as well as the advantages and faults of each process. As soon as the pyrites is converted into sulphat of iron, whether by roasting or by spontaneous efflorescence, it begins to be gradually decomposed by the lime and magnesia that may happen to be in the ore, therefore the less there is of these two earths, the greater *ceteris paribus* will be the produce of alum. Clay is incapable of decomposing sulphat of iron; but by exposure to the air, especially when assisted by the action of heat, the metal becomes highly oxygenated, and is no longer combinable with the acid which then unites with the clay, as being the substance in the ore of next affinity. Hence arises the advantage of the practice at Flone of roasting the ore *after* the formation of the sulphat of iron. We have already seen in § 1. that sulphat of alumine, even with excess of earth, is soluble in water, but that it becomes insoluble on the addition of potash; on this account, therefore, coal, which contains little or no potash, is a far preferable fuel for roasting the ore than wood which yields a great deal, as all the alum, thus rendered incapable of extraction by lixiviation, is lost. The bitumen in the ore, however, diminishes the consumption of wood, and the lixivium consists of the sulphats of iron, of alumine, of lime, and magnesia. By long boiling and evaporation the iron becomes so far oxygenated, that the addition of an alkali will decompose the sulphat of iron, rather than the sulphat of alumine. If the alkali is ever so little in excess, the aluminous sulphat will be the next decomposed; this is therefore to be carefully avoided. Nor is the kind of alkali a matter of indifference, for since only ammonia and potash are capable of forming crystallizable alum, it would appear that the use of soda in the English manufactories might be advantageously superseded by potash; indeed the chief use of the kelp seems to consist in the potash which this impure soda contains. The principal thing to be attended to in the boiling down is to bring the liquor to such a degree of concentration, that the alum shall be deposited with as little as possible of the other salts.

The mother-water, when thrown away, holds in solution sulphats of potash or soda, and sulphat of magnesia, the extraction of which was made the subject of one of Lord Dun-

donald's patents, but we believe the profits have not yet answered the expence.

The nature of alum, and consequently the true theory of its manufacture, has only been known since the publication of Vauquelin's excellent memoir on the subject in the *Annales de Chimie*; it is not surprising, therefore, that all the long-established processes should be more or less defective. Perhaps the following method would be found to combine more advantages, and be subject to fewer inconveniences than any which has been hitherto put into practice. The ore should be first slightly roasted with coal to drive off the bitumen, and forward the decomposition of the pyrites, which may be further accelerated by moderate waterings, and exposure of fresh surfaces to the action of the air. When saline efflorescences appear at the top of the heaps of ore, and their interior, upon being dug into, also seems penetrated with white saline particles, let the ore be disposed in alternate strata with coal, and again roasted, so as to decompose as much as possible of the sulphated iron, and combine the acid with the clay; the slower and more gently this process can be carried on, the more completely will its object be answered. The lixivium obtained from this roasted ore will consist chiefly of sulphated alumine, nearly saturated with earth, but, on account of the absence of potash, perfectly soluble. By the subsequent boiling and agitation, part of the sulphat of iron would be decomposed, and this oxydation of the iron might perhaps be still further effected, by pouring the liquor through heaps of faggots, exposed to the wind, as is done in the *houes of graduation* for brine in France and Germany. The ferruginous and selenitic sediments being now allowed to settle, the clear liquor ought to be transferred into another reservoir, and there mixed with a hot solution of acidulous sulphat of potash, such as remains after the distillation of aquafortis from nitre and sulphuric acid; crystals will be immediately deposited of an alum much purer than common; and these, by a further clarification, may be made equal to that of La Tolfa.

§ 5. *Manufacture of Alum by Chaptal's process.*

An attempt had been made, but with little success, at the manufactory of Javelle near Paris, to prepare alum by the direct combination of its constituent principles; but it was not till the admirable and decisive experiments, in the large way, by Chaptal, published by him in the genuine spirit of philosophic liberality, that the practicability of this method could be said to be established. According to the modern way of preparing SULPHURIC ACID, the requisite proportions of sulphur and nitre being mixed together, are brought to combustion in a closed chamber lined with lead; the sulphur is thus acidified and converted into vapour, which by degrees unites with the water that overspreads the floor of the chamber, and forms a liquid, diluted, sulphuric acid. A similar process was instituted by Chaptal, only substituting dried clay for the water; the result of which was so favourable, that a large manufactory on the same plan was set on foot; which, having continued in full activity for several years, and producing alum only inferior to that of La Tolfa, merits a particular description.

The chamber in which the combustion is performed is 91 feet long, 48 feet wide, and 31 feet in height to the pitch of the roof. The walls are of common masonry, lined with a moderately thick coating of white plaster; the floor is a pavement of bricks, set in a mortar, composed of baked and unbaked clay; and this first pavement is covered by a second, in which the bricks are made to overlie the joints of the lower ones, and are themselves firmly connected to each other by a cement, composed of equal parts of pitch, tur-

pentine, and wax, made boiling hot, and poured between the joints instead of mortar. The roof is of wood, and the beams are set at much less distances than common; they are also channelled with deep longitudinal grooves, for the purpose of receiving the planks that fill up the space between the beams; so that the whole of this great area of carpentry does not present a single nail. The chamber thus constructed was covered on the sides and top with a layer of the cement just mentioned, applied as hot as possible so as to penetrate into all the pores of the wood and plaster; three more successive layers were then laid on, and the last was polished so as to present an uniform, even, solid face. In order to prevent the wood-work of the ceiling from warping, it was covered on the outside with a thick coating of cement, and a light roof of tiles was laid over the whole. By substituting this cement for a lining of lead, a vast saving was effected in the first expence; and it has been found, by long experience, to require much fewer repairs than even lead itself.

The clay ought to be of the purest kind, such as pipe-clay; that it may contain neither lime nor magnesia, and as little as possible of iron. It is to be tempered with water, and made into balls five or six inches in diameter; these being dried in the sun, are afterwards calcined in a furnace; the first effect of the heat is to blacken them, but soon after they become red hot, the carbonaceous matter which causes the blackness is burnt out. Being thus withdrawn from the fire and cooled, they are broken down into small fragments, and spread on the floor of the chamber. In this state they are exposed to the vapour of sulphuric acid from the combustion of sulphur and nitre; and in a few days the pieces are observed to crack and open, and to be penetrated with slender saline crystals. The earth being at length covered with efflorescences, it is removed from the chamber, and exposed to the air under shelter of a shed, that the acid may obtain its highest degree of oxygenation, and become thoroughly united with the earth. It is now lixiviated, and the liquor contains, in solution, little else than acidulous sulphat of alumine: this being boiled down to the proper consistence, a solution of sulphated potash (being the residue in the pots of combustion from which the sulphuric acid was produced in the chamber, and consisting of the alkaline base of the nitre combined with some of the sulphuric acid) is poured in, and the liquor being then transferred into a large vat, perfect crystals of alum are shortly deposited, which are afterwards refined in the usual manner.

The advantages of this process are numerous. It may be carried on whenever a supply of proper clay can be had. The space taken up by the works is much less extensive than what is required according to the common methods. The whole manufacture is performed in at most one-third of the time usually necessary. A large quantity of fuel is saved. The extraneous salts in the mother-water are fewer; an important use is made of the residual sulphat of potash; and lastly, the alum itself is much purer, and almost equally well adapted to fix the delicate dyes as that of La Tolfa, the commercial price of which is generally about double that of the English alum.

§ 6. *Brunswick Alum.*

The dilute red colour of the roch alum, and the flesh-coloured efflorescences with which its crystals are covered, being its distinguishing character among the merchants, occasioned two brothers of the name of Gravenhorst to manufacture, some years ago, a spurious imitation of it at Brunswick. We know not whether the manufacture is still carried on or not; but if it is, the public will be benefited by the communication of an easy method of detecting the counterfeit, more

especially as the rock alum is the kind used in medicine, and the Brunswick imitation of it contains *arsenic*. The external appearance of the two sorts differs but little. The taste of the Brunswick alum is less styptic than that of the rock alum, it is less soluble in water, and when heated to redness, it loses only 37.5 per cent. of its original weight, while the other loses 50 per cent. The rock alum, when exposed to the blow-pipe, becomes opaque, swells, foams, and is converted into a spongy white mass. The Brunswick alum, on the contrary, swells less, scarcely foams at all, but melts, and becomes of a green colour, exhaling at the same time an arsenical vapour. Again, the precipitate from a solution of rock alum by potash or soda, being mixed with borax, fuses before the blow-pipe into a white or yellowish white; whereas the Brunswick, by the same treatment, affords a violet-coloured globule; and in fact it is nothing more than common alum, containing a little cobalt and arsenic.

§ 7. *Comparison of English, Roman, Levant, and French Alum.*

The Roman alum, manufactured at La Tolfa, is the purest and dearest of all; it is in pieces about the size of a walnut, shewing more or less of its crystalline form, and is opaque, on account of a farinaceous efflorescence with which it is covered. The Levant or rock alum appears in fragments of nearly the same size as the former, but in which the crystalline form is more obscure; it is externally of a dirty rose-colour, and internally exhibits the same tinge, but clearer. Smyrna is the place whence it is usually shipped for Europe; but it was anciently made at Roccha, or Edeffa, in Syria, whence its commercial name rock-alum. The French alum, that is, Chaptal's, described in § 5. is in small, clear, colourless crystals. The English is in large, irregular masses, considerably harder than the others. Equal portions of all these kinds, being exposed in a muffle to a red heat, were weighed after the intumescence was over, and the loss by calcination in the Roman alum was 50 per cent.; in the Levant alum 40 per cent.; in the French alum 57 per cent.; and in the English 47 per cent. Of pure water, at 114° Fahr. Roman alum required 14 times its weight for solution; Levant alum required 12 parts; French alum 13 parts; and English 15 parts.

Equal parts of these four kinds of alum being dissolved separately in water, the same quantity of prussiated lime was added to each solution. That of the English alum became slightly blue at the end of a few minutes, as was also that of the French alum, though the tint was rather lighter; after some time the Roman alum became faintly blue; but the solution of Levant alum was only lightly yellow, the natural colour of the prussiated lime. After two days an inappreciable quantity of blue precipitate was deposited from the English alum, rather less from the Roman and French, and only a few atoms from the Levantine; the three first solutions were of a bluish green tint, but the last was a very dilute yellow.

Equal parts of the four sorts were dissolved separately in pure water, and their earthy base was precipitated by an excess of ammonia. The precipitate from the Roman alum was of a pure dead white; that of the Levantine and French was nearly equal to the Roman; but that of the English was of a just perceptible bluish tint. By calcination in a red heat, they all at first became blackish, and ended with being perfectly white.

Hence is apparent the superiority of the Roman alum, and the inferiority of the English, when used as mordants for the most delicate colours: for other colours, and for the various uses besides to which alum is applied, each kind may

be used indifferently. The English possesses less water of crystallization than the Roman or French; and a given weight of it will go further than the same quantity of any of the rest, as 12 per cent. is to be deducted from the Levantine, on account of the reddish insoluble sediment with which it is contaminated.

§ 8. *Historical notice of the introduction of alum-making into Europe.*

The ancients appear to have been acquainted only with the native plume alum, which they procured from Lipari, and the neighbouring volcanic islands. In the 12th, 13th, and 14th centuries it was manufactured at Edeffa (Roccha) in Syria, in the vicinity of Constantinople, and at Phocæa (Foya nova), not far from Smyrna. Bartholomew Perdik, a Genoese merchant, who had often visited Roccha, discovered, about the year 1450, a vein of alum ore in the island Iscia, and there established the first European manufactory of alum; soon after John de Castro discovered the body of ore at La Tolfa. Establishments were then made at Viterbo, Volaterra, and other places in Italy, with such success, as induced Pope Pius II. to prohibit the importation of Oriental alum. In the 16th century this art was introduced into Germany and Spain; and a little before its conclusion the English alum-works at Whitby were instituted by Sir Thomas Chaloner, who had the honour of being personally excommunicated by the reigning pope on this very account. The earliest of the Swedish works dates no higher than 1637. Macquer's *Chymisches wörterbuch* von Leonhardi, art. *Alaun*. *Annales de Chimie*, vols. viii. xiv. xxii. xxix. Plinii. *Hist. Nat. lib. xxxv. c. 52.* Bergman's *Essays*, vol. i. *Mémoires de l'Acad. Royale*, vol. v. *Encyclopédie Method.* art. *Alun*.

ALUM, in *Chemistry, Materia Medica*, &c. See SULPHAT OF ALUMINE.

ALUMINE.—PURE EARTH OF ALUM.—PURE CLAYEY OR ARGILLACEOUS EARTH. *Alumine*,—*Terre d'alun*.—*Terre argilleuse*, Fr.—*Thon-erde*, Germ.

The word alumine has been adopted, without alteration, from the modern French nomenclature, by the majority of English chemists, as the technical name of pure argillaceous earth, on account of its being generally procured by the decomposition of alum, when required to be in a state of extreme purity.

Next to silice and lime, alumine appears to be the most commonly occurring earth in those stony or earthy masses, of which the globe, as far as we are acquainted with it, is principally composed. It forms the essential, though seldom the greatest part of all kinds of clays, giving to them the property of ductility or plasticity when mixed with water. When in a state of more intimate combination with silice it loses its quality of plasticity, and gives to the minerals in which it enters, the characters of opacity, of hardness inferior to that required for striking fire with steel, of that odour known by mineralogists under the name of earthy, and of that absence of crystalline form which is called amorphous; such are the immense masses of slate and argillaceous schistus that abound in almost all mountainous tracts, the boles, the colorific earths, the roadstones and clay porphyries. Alumine, however, occasionally, though very rarely, enters in large proportion into crystallized minerals, and then in its external characters of hardness, transparency and lustre, approaches very nearly to silice: such is the adamantine spar, inferior only in hardness to the diamond, and which contains from 50 to 90 per cent. of alumine: such also is the sapphire, which by the analysis of Klaproth appears to contain no less than 92 per cent. of

pure alumine. These, however, which are more properly the mineralogical than chemical characters of alumine, will be treated of more at large in the subsequent mineralogical articles.

Pure alumine, in a state proper for chemical experiment, has hitherto never been found native, and it is only of late that chemists have discovered the method of obtaining this earth sufficiently free from foreign admixture. The method of Bergman and his contemporaries was to decompose a solution of purified crystals of alum by an excess of carbonated potash, or soda, and to wash the earthy precipitate in repeated quantities of distilled water, till it came off perfectly tasteless and pure; a white uniform soft matter was thus obtained, which was supposed to be carbonated alumine, and this by drying in a heat below that of redness, was deprived of its acid and water, and was then esteemed pure alumine. The insufficiency of this method had begun to be suspected for some time, however, particularly from the appearance of sulphurated hydrogen, when alumine thus purified was heated with charcoal, and afterwards moistened with a diluted acid, and the admirable memoir of Vauquelin on alum, (which has already been referred to under that article) not only established the validity of these suspicions, but pointed out the method of avoiding the errors of his predecessors, and thus introduced a very important improvement in the difficult art of chemical analysis. Alum has already been shewn to be a triple compound of alumine, potash and sulphuric acid in excess, and when this excess of acid is taken away, either by the addition of alumine or of an alkali, an insoluble salt is produced differing from alum only in the proportion of its earthy base; now the ease with which a salt is decomposed depends very materially on its solubility, when, therefore, we add gradually to a solution of alum a solution of carbonated alkali, the first effect is to neutralize the excess of acid, and the precipitate consists principally of the insoluble salt just mentioned; a further quantity of alkali, especially if assisted by heat, will effect the decomposition of part of the salt, but in proportion as this takes place the residue becomes mixed with the alumine, and thus is covered from the further action of the alkali. This being the case, it is obvious that no subsequent washings can do more than separate the sulphated potash; and therefore the residue, instead of being pure alumine, contains besides a variable proportion of earthy alum, from which last proceeds the sulphur observable on heating it in a close vessel with charcoal.

The only way by which alum can be made to yield its earth in a state of sufficient purity for delicate chemical experiments, is the following. Take any quantity of Roman alum, and dissolve it in lukewarm distilled water, filter the solution, and set it to crystallize. When by cooling and spontaneous evaporation, a sufficient portion of this purified alum is deposited, take it out and redissolve in cold distilled water; to this solution add liquid caustic ammonia, a white precipitate will be thrown down, and continue the gradual addition of ammonia till no farther precipitation takes place; heat the liquor then nearly to boiling for a few minutes, add more water, and throw the whole on a paper filter; in proportion as the fluid drains off add water, till it passes through quite tasteless. The precipitate, while yet in a pulpy state, is to be removed into a flask, and digested with muriatic acid till it is dissolved. The muriatic solution being then concentrated by very gentle evaporation, will at length deposit crystals of alum, which are to be removed, and this process is to be continued till the liquor ceases to yield any more. Nothing now but pure alumine remains in the solution, the potash and sulphuric acid being got rid of, at the expence of a little of the alu-

mine in the crystals, the liquor is therefore to be diluted with water; and ammonia fully sufficient for the decomposition of the muriated alumine being then added, the process of filtration and edulcoration is to be gone through as before, and the result will be pure alumine. On account of the length of this method, and the possibility that even after all a very minute proportion of sulphated potash may still remain, it has been the practice of late with Vauquelin and Berthollet to procure their pure alumine from such of the natural clays as contain only silice and alumine, by digestion in muriatic acid and decomposition of the solution by ammonia.

Pure alumine, obtained by the above methods, is opaque, of a snow white colour, a smooth somewhat unctuous feel, has no smell, even when breathed upon, or moistened with warm water, nor any proper taste; when placed upon the tongue, however, it absorbs all the moisture with which it finds itself in contact, and thus occasions a peculiar sensation of astringency. It is readily diffusible, and remains for a long time suspended in water, but appears to be totally insoluble in this fluid. Its specific gravity is variously estimated, according to the degree of delicacy, by Bergman it is reckoned 1.305, while Kirwan allows it as much as 2.0. After being thoroughly dried in a heat just not sufficient to destroy its plasticity, it is capable of absorbing $2\frac{1}{2}$ times its weight of water, without allowing any to drop out, and the water thus mixed is retained more obstinately at the usual atmospheric temperature by alumine than by any other earth; a freezing cold however causes this earth to contract remarkably, and thus squeeze out a large proportion of its water.

Alumine is the only earth that possesses the property of plasticity, or of being kneaded up with water into a soft ductile paste, capable of being formed by the hand or the potter's wheel into any shape that may be required; the plasticity therefore of all the natural clays is owing to their aluminous part; nor is this property destroyed even by a very large admixture of other earths; in the finer kinds of pottery scarcely a fourth of the whole mass is pure alumine, and yet its plasticity is unimpaired. If a piece of tempered clay is dried gently in the air, it retains its form, but becomes quite brittle; its former ductility may, however, be restored by again kneading it with water. If exposed to a red heat it hardens, contracts in all its dimensions, becomes more compact, and of greater specific gravity, and is no longer plastic, nor can this property be restored to it by any other means than by solution and precipitation; hence bricks or pottery ware, after having been baked, if pounded ever so fine, are no more capable of forming a paste with water.

The action of caloric on alumine is accompanied by some interesting phenomena which deserve mentioning. If the purest plastic alumine is exposed to a low red heat, it becomes of a bluish black colour, especially on the inside, as is manifested by breaking a piece across that has been thus heated; as soon as this colour is perceived the plasticity is destroyed, a fact that renders it probable that this property of alumine depends on something else than mere water. By a further increase of the heat with access of air, the carbonaceous colouring matter is burnt out, and the alumine acquires a resplendent white colour, becoming at the same time harder, denser, and of less bulk; all these changes advance in gradual progression in proportion to the heat; and after it has thus experienced the full effect of our most powerful furnaces, it will be found to be so hard as to give fire with steel, and reduced to nearly one half of its original bulk. Upon this last property is founded the use of *Hedgewood's PYROMETER*, for measuring the higher degrees of heat. The

decrease of bulk is in part occasioned by the expulsion of the last particles of water; but from the augmented specific gravity of the alumine, it is plain that an actual condensation or approximation of molecules takes place, as is observable in various other porous substances previous to fusion. Whether any artificial heat is able to bring this earth into real fusion is as yet dubious; for though Lavoisier, by means of a blow-pipe charged with oxygen gas, reduced a piece of alumine to a pasty semi-fluid state, yet it is probable, as the earth was obtained from alum, that a minute portion of potash might still be contained in it, and thus act as a flux.

Alumine has a strong affinity for metallic oxyds, especially the oxyd of iron; hence arises the difficulty, and indeed almost impossibility, of obtaining alum free from iron in the great way, because all natural clays and aluminous ores contain more or less of this metal. The only way of accurately separating these two substances is by digestion in caustic potash or soda, which will dissolve the earth but not the oxyd.

These two substances are also capable of acting on each other in the dry way at high temperatures; and some important experiments on this subject are recorded by Achard and Kirwan, from which it appears, that when the proportion of alumine exceeds that of the oxyd of iron, the mixture is in all cases very difficultly fusible; that when the proportions of the ingredients are equal, and especially when the iron predominates, the result, after exposure to a heat of about 160° Wedgewood, is a dark-coloured vitreous slag.

The attraction too that subsists between alumine and vegetable or animal colouring matter, is singularly powerful. Thus, if, to a watery infusion of cochineal or madder, a few drops of a solution of alum are added, a decomposition shortly takes place, and the whole of the tinging particles unite, and are precipitated together with the aluminous base of the earthy salt, leaving the supernatant liquor wholly colourless. Fugitive colours also, by this combination, become of sufficient permanence to resist for a long time the changes to which they are subject: hence is explained the preparation of the *LAKE pigments*, and the theory of *Mordants* in the art of *DYING*.

In the direct way sulphur appears to contract no union with alumine; and the hepatic gas that is separated by an acid from alum, after having been heated with charcoal, is no longer a decisive evidence of sulphuret of alumine, since the discovery of the necessity of potash to the very constitution of common alum.

Upon the gaseous substances alumine has not been observed to produce any change, although Humboldt has published (*Annales de Chemie*, vol. xxix.) a long and plausible memoir, to shew that alumine absorbs the oxygen of the atmosphere, and hence produces an important effect in the economy of vegetation. It is true, indeed, that many natural clays will deoxygenate atmospheric air; but this is solely owing to the carbonaceous matter, and oxyd of iron that they contain, it having been proved by accurate experiments, instituted for this purpose by Theod. Saussure and others, that pure alumine has no effect whatever on oxygen gas or atmospheric air.

All the acids are capable in particular circumstances, of combining with alumine; but these combinations are not accomplished with the same ease as those between the acids and alkaline earths. The stronger mineral acids will take up alumine from clay by digestion at a boiling heat, but the vegetable and other weaker acids will not readily effect a solution, except the alumine is presented to them recently precipitated by an alkali from sulphuric, nitric, or muriatic acid. All the aluminous salts are decomposed with precipitation of the earth by the caustic or carbonated alkalis, or alkaline

earths. For further particulars see the salts under their respective acids.

Ammonia has not yet been observed to exert any action on pure aluminous earth; but both potash and soda, when caustic, will dissolve it without any difficulty. This may be done by evaporating to dryness, and igniting in a silver crucible, a mixture of caustic alkali and alumine, and then lixiviating the mass, or merely by boiling some fresh precipitated alumine in a watery solution of the alkali. This alkalinized alumine has of late been recommended as a preferable mordant to common alum in the fixing of those colours that are injured by the presence of sulphuric acid. To separate alumine from its solution in caustic alkali, it is necessary to add nitric or muriatic acid in sufficient quantity to neutralize the alkali and dissolve the alumine, and then to precipitate the earth by caustic ammonia.

The action of barytes on alumine is analogous to that of the alkalis, yet presents some peculiar characters. When a solution of caustic barytes in water is added to a liquid muriat of alumine, the first effect is the appearance of a precipitate, owing to the decomposition of the salt by the barytes; if this salt, however, is added in excess, the alumine is redissolved by it, and the liquor becomes clear.

Again, if equal parts of newly precipitated alumine and caustic barytes are boiled together in a quantity of distilled water sufficient to take up the barytes, about half the mixture will be dissolved, and upon analysis the insoluble residue will be found to consist of alumine, with a small proportion of barytes, while the solution will consist of much barytes and a little alumine. By adding to the liquor some muriatic acid, to engage the excess of barytes, a flocculent precipitate will be deposited, consisting of the two earths, nearly in the proportion of the original insoluble residue. Hence it appears that alumine combines with barytes into a salt which is insoluble in mere water, but is capable of being rendered soluble therein by the assistance of barytes. In the dry way, at about 150° Wedgewood, any mixtures of the two earths in which the alumine preponderates remain pulverulent; but when the barytes is three or four times as much as the alumine, the powder concretes into a hard mass, without, however, shewing any signs of fusion. In order to decompose barytic alumine, dissolve the whole in muriatic acid, and add caustic ammonia; the alumine alone will be precipitated.

Strontian produces the same effect on alumine as barytes, but more feebly; the action of these two substances in the dry way, on each other, has not yet been the subject of experiment.

It appears highly probable that lime has a similar affinity for alumine, as the rest of the alkaline earths possess; the only experiment, however, upon the subject, is one of Morveau; he mixed equal parts of muriat of alumine and muriat of lime in solution, and immediately a precipitate took place, which was insoluble by an excess of acid; this has been since repeated by Darracq, a pupil of Vauquelin, without effect, the liquor remaining perfectly limpid; hence it is probable that the alumine of Morveau was not quite free from sulphuric acid, and that the insoluble precipitate was merely selenite. In the dry way lime and alumine in any proportions are infusible, except by means of a blow-pipe, charged with oxygen gas.

The action of magnesia on alumine is not yet fully ascertained: it appears, however, from Mr. Chenevix's experiments, that the ammoniaco-magnesian triple salts, are formed with difficulty, when alumine is present, and that magnesia prevents, in a great measure, the solubility of alumine in the caustic fixed alkalis. This combination of the two

earths is, however, soluble in muriatic or mineral acids, and may then be decomposed either by the triphosphuret of soda or of ammonia, which will precipitate the alumina, and retain the magnesia in solution, or by an alkaline prussiat, which will also separate the alumina while the prussiated magnesia remains dissolved. In the dry way, according to Kirwan, magnesia and alumina at 150° Wedgewood have no action on each other in any proportions.

A considerable degree of affinity exists between silica and alumina, and the unsuspected formation of this compound in many analytical experiments on minerals has often produced a number of deceitful and embarrassing appearances, which have vitiated the results of many a laborious analysis. Chemistry is, therefore, indebted to Klaproth for shewing, that when to a solution of pure silica in caustic potash is added a solution of alumina equally pure in the same menstruum, the liquor immediately assumes a reddish brown colour; and after standing an hour or more, coagulates into a thick opaque whitish jelly. This jelly, by the addition of a little warm water, is resolved into a fluid, and being then mixed with muriatic acid, to the exact saturation of the alkali, a copious precipitate is deposited, consisting of the two earths, in a state of combination; if now a slight excess of acid is dropped in, the silica as well as the alumina, will be perfectly dissolved. Carbonated potash will again cause the precipitate to appear, and this even when separated by filtration and dried, will be still entirely soluble in dilute sulphuric acid, without the smallest deposition of silica. If the sulphuric solution is now gently evaporated, crystals of alum will be deposited, and the remainder will assume the form of a clear jelly, the surface of which, after a few days, will be covered with crystalline pyramids; and in order to shew that it is really silica mixed with alumina, which has thus repeatedly been dissolved in acids, nothing more is necessary than to mix this jelly with a large quantity of water, and digest it for some while in a moderate heat, stirring it repeatedly

at the same time, when the liquor will become turbid and pure silica will be deposited. In the dry way, according to Kirwan, equal parts of alumina and silica at 160° Wedgewood concrete together, but shew no signs of fusion.

Alumina is as yet a pure chemical element, never having been composed or analysed. From its affinity with colouring matter, and its blackening in a low heat, Baron was of opinion that it was of a metallic nature, and even Lavoisier entertained the idea that it might be a metallic oxyd, whose component elements were united together by a very powerful affinity. Beaumè considers the earth of alum as essentially the same with silica, being led into this mistake by fusing rock crystal repeatedly with potash, and always obtaining alumina; this experiment of Beaumè was repeated by Scheele, who found indeed that it was true whenever an earthenware crucible was made use of, but perceiving the crucibles corroded internally after every process, he suspected that the alumina was furnished by the action of the alkali upon them; in proof of which he repeated the fusion of silica with potash in an iron crucible, and as might be expected, did not procure a particle of alumina.

The uses of pure alumina are wholly confined to the laboratory; it gives, however, their peculiar character to all clays; every thing, therefore, that depends on the cohesiveness and plasticity of these substances when fresh, and their hardness after being baked, may be fairly attributed to the alumina which they contain; hence, it is the basis and material of all the arts of pottery, from the common brick to the finest porcelain, and these include more of the comforts and elegancies of life than are perhaps dependent on any other substance in nature.

Journal de Physique, vol. lii.—Scheele's *Essays*.—Klaproth's *Analytical Essays*.—Kirwan's *Mineralogy*, vol. i.—*Annales de Chimie*, vols. xxviii. xxix. xxx. xl.—Macquer's *Chimisches Wörterbuch*, vol. vi.—Beaumè *Chymie Experimentale*, vol. i.

Ammonia

AMMONIA, or VOLATILE ALKALI. Alkali volatile, *Ammoniaque*, Fr.—*Alkali fluchtiges*; *Harnsalz*, *urinsalz*, *fluchtiges*, Germ.

Under the article ALKALI we noticed some of the peculiar properties of the *volatile* alkali whereby it is distinguished from the *fixed*. We shall, in this place, give a more particular account of ammonia, which requires considerable notice from its high importance as a chemical agent, and from the numerous researches which have been made into all its properties and combinations, with more success than perhaps has fallen to the share of any other substance of equal value to the chemist.

As ammonia is never found native in an uncombined state, and is, in most cases, a *product* of various natural or artificial processes, we shall refer the reader to the articles ANIMAL matter, CARBONAT of ammonia, MURIAT of ammonia, and salt of HARTSHORN, for every thing that relates to the natural history of this alkali and its production in the large way as a manufacture, and shall here confine our-

selves to the purely chemical description.

The volatile alkali (like so many other chemical agents) when perfectly pure and uncombined, is only known to us in the form of a gas; and, as it is the only one of the alkalies which is capable of assuming this form in any common degree of heat, the term *alkaline* air, used by Dr. Priestley and many other chemists, is synonymous with ammoniacal gas. This gas has the following properties: It possesses a most pungent smell, which, when strongly snuffed up the nostrils, provokes to coughing, and gives a temporary sense of suffocation, owing to the constriction of the fauces which it produces. To the taste it is highly stimulating and acrid, and quickly corrodes the skin of the tongue and lips, so that it cannot be taken into the mouth in the undiluted form with safety. It is speedily fatal to animals that are immersed in it, and it extinguishes a taper; but the flame of this last is first enlarged, and becomes of a pale yellow colour. Ammoniacal gas is, next to hydrogen, the lightest of all the gaseous bodies. Its specific

gravity may be reckoned about 0.735 (distilled water being 1000.) whereas atmospheric air is 1.23, or nearly twice as heavy as alkaline air. The absolute weight of 100 cubic inches of this gas at 30° bar. and 61° therm. is reckoned by Kirwan to be 18.16 grains. It is highly dilatable by heat, and at a very high temperature is decomposed. It is also very rapidly and copiously absorbed by most liquids, especially by water, and hence it cannot be kept over water; but, for the purposes of experiment, it must be confined in well closed bottles or over mercury.

Ammoniacal gas is given out during the distillation of almost every animal, and some vegetable matters, but it cannot in this method be procured sufficiently pure for chemical experiments. For this purpose the muriate of ammonia (or common crude sal ammoniac) is the most convenient material for yielding the gas. This salt is readily decomposed by quicklime, which last unites with the muriatic acid of the salt, and expels the ammonia in its purest and most caustic form of gas. The decomposition is so speedy, that a very pungent smell of volatile alkali is perceived merely on rubbing together these two substances. If one part of dry sal-ammoniac is mixed with two parts of well burnt lime (or less if the lime is good), put into a dry phial or earthen tube, and heated gently, the ammoniacal gas rises in great abundance, and may be directed by means of a bent tube under a jar full of dry mercury, where it may be preserved in the gaseous form for any length of time. Many of the metallic oxyds, especially minium or litharge, will supply the place of the lime and expel the gas from the muriate of ammonia in very great purity. A still more simple method of obtaining the gas is to apply a gentle heat to the liquid or watery solution of ammonia, which expels from it the alkaline air that the water had previously been made to absorb at a lower temperature. It may be remarked that the discovery of ammonia in a gaseous form, as well as many of the most interesting properties of this alkali, is due to Dr. Priestley.

Ammonia, dissolved in water (forming the *liquid ammonia* of modern chemists, the *fluor volatile alkali* of former times, or the *aqua ammonia pura* of the London Pharmacopœia) is the form in which the caustic ammonia is the most familiar to us, and in which many of the properties of the alkali can be most conveniently examined. This, when pure, should be perfectly transparent and colourless as water, should have the strong burning taste and pungent smell of ammonia, and should give no effervescence with acids. This latter test deserves attention on account of the variety of volatile alkaline liquors that are prepared, all of which, except the *aqua ammonia pura*, contain more or less carbonic acid, and are much milder in all their sensible properties.

Ammoniacal gas is absorbed by water with great rapidity, and at the same time a considerable quantity of heat is given out from the gas, which is sufficient to raise the temperature of the water, and to be sensible to the hand. The same gas, when put in contact with ice, melts it with apparently as much rapidity as if the ice were put into a fire, and is greedily absorbed, at the same time that considerable cold is produced. At a moderate temperature water may be made to dissolve nearly one third of its weight, or many hundred times its bulk, of this gas. The bulk of the water is so much increased by this process that it becomes specifically lighter than distilled water. Mr. Davy, in his experiments on this subject, (*Researches into nitrous Oxyd*, 1800.) found that, at the temperature of 53°, 100 grains of liquid ammonia, holding in solution 9.503 grains of the alkali, gave a specific gravity of .9684. When

perfectly saturated, 100 grains of the liquid alkali contained 25.37 grains of ammonia, which is full one-third of the weight of the water employed, and had the specific gravity of .9054. Other writers, however, make the specific gravity of saturated liquid ammonia as little as .897. The gentle heat of a spirit lamp again expels the alkali in the form of gas, but the last portions require a strong ebullition before they can be made to quit the water. When liquid ammonia is exposed to a very intense cold, sufficient to freeze mercury, as Messrs. Fourcroy and Vauquelin have observed, it becomes a grey semi-transparent mass, of the consistence of a very stiff jelly, and with scarcely any odour.

The liquid ammonia is prepared in two methods. That which is the oldest and the most usually practised, is to mix together quick-lime, muriate of ammonia, and water, and to distil the mixture with a gentle heat. The London Pharmacopœia orders for the preparation of the pure liquid ammonia, two pounds of lime slacked in two pints of water, and one pound of sal ammoniac, which are to be mixed with six pints of hot water, and to be kept in a covered vessel till cold. The liquor is then to be distilled, and the first pint which comes over is the pure liquid ammonia. This liquor, however, is by no means saturated with the alkali, for during the heat, even of a gentle distillation, the solvent power of the water is much lessened. The most elegant and effectual way of preparing this liquor is to disengage the gas from the *dry* materials; and by using the beautiful APPARATUS of Woulfe, to cause the alkaline air to pass into cold water where the absorption is much more speedy; and, if necessary, the increase of temperature produced by this absorption may be prevented by surrounding the bottles with ice. The proportions of the ingredients here used, may be two parts of lime slacked in as little water as possible, mixed with one part of dry muriate of ammonia and put into a retort for the production of the gas; and, in the condensing bottles, about as much water as the weight of the sal ammoniac employed. The liquid ammonia is known to be thoroughly saturated with the alkaline gas, when the bubbles pass through the water undiminished, and no further absorption takes place.

Many of the combinations of ammonia with different chemical agents are highly curious and important; but as most of them produce alterations which depend on the decomposition of this alkali, they will be better understood by the reader, if we first relate some of the multitude of facts by which the analysis of ammonia has been ascertained. The constituent parts of the volatile alkali are, hydrogen (or the basis of inflammable air), and azot (the basis of phlogisticated air), the proportions of these two substances are, about 29, (in weight) of the former, and 121 of the latter; and it may be remarked that this is the only simple combination of these two substances with which we are certainly acquainted. The proofs of this analysis we shall relate nearly in the order of discovery by the various eminent chemists who have thrown light on the subject.

Dr. Priestley was the first who remarked a very interesting change produced on alkaline air by means of electricity. For this purpose he confined a known portion of this gas in a jar over mercury, and passed a number of successive electric explosions and sparks. He found after every shock that the bulk of the confined air increased, and continued to do so till it had expanded to nearly three times its original bulk. The air was now much altered in its properties, for on letting up some water into the jar, scarcely any of the gas was absorbed, whereas before electrization every par-

ticle of it would have rapidly united with this fluid. The gas was found to be highly inflammable, and exploded when mixed with common air, in the same manner as the inflammable air procured from iron by an acid. The gas likewise after being a short time in contact with water had entirely lost its alkaline smell. The colour of the electric spark taken in the alkaline air was red, but white in the centre, when any considerable explosion had been taken.

The same eminent chemist likewise found alkaline air to be decomposed by passing through a red hot tube, though not so completely as by the electric spark. In performing this experiment he found the tube, through which the alkaline vapour had passed, lined with a black matter, and the liquor collected after this distillation also obscured with the same substance. This is probably owing to some fissure in the tube which admitted carbonaceous matter from the hot coals, as we shall mention hereafter. Another property of alkaline air, highly illustrative of its composition, is the reduction of several metallic oxyds which it effects when they are heated in contact with it. Dr. Priestley confined some litharge, or oxyd of lead, in this gas, and by heating it with a burning lens (a method of applying heat of all others the most accurate), he revived the lead in its metallic form, and a quantity of phlogisticated air remained. The red mercurial oxyd, or *red precipitate*, was heated in the same manner, and the mercury was revived, and at the same time a considerable quantity of *water* was produced so as to run down in drops on the sides of the jar, which before appeared perfectly dry. The red precipitate, however, gave out during this reduction a large quantity of uncombined dephlogisticated air, which appeared in the residual air after the reduction was completed. This, in another experiment with the same materials, united with some of the inflammable air contained in the alkaline gas and caused a considerable explosion. The antiphlogistic theory will readily explain the production of *water* during the experiment from the union of the oxygen of the red precipitate, and the hydrogen of the ammoniacal gas; but this fact more properly belongs to the subjects of *WATER* and *PHLOGISTON*.

These experiments were soon repeated by various chemists, and with similar results. Landriani found, that in passing ammoniacal gas through a tube heated white hot, the alkaline properties were entirely lost, inflammable air was produced, and likewise a small portion of carbonic acid sufficient to give a precipitate with lime water.

Van Marum, in his experiments on the effect of electricity on the gases, found the same results with ammoniacal gas that we have just mentioned. Two cubic inches and seven eighths of the alkaline gas were enlarged to four inches, and the air was no longer absorbed by water, and was highly inflammable.

Whilst the properties and composition of the volatile alkali were made the subject of so much ingenious and successful research by Dr. Priestley, they received full elucidation by the labours of one of the most eminent of the French chemists, M. Berthollet.

This excellent experimentalist found, that when the oxygenated marine acid is added to liquid ammonia perfectly caustic, a considerable effervescence takes place, and a quantity of gas is collected from the two liquids, which, when examined by the usual chemical tests, proves to be pure azotic gas. At the same time the oxygenated acid loses its peculiar pungent smell, and becomes converted into simple marine acid. The explanation given of these phenomena is, that the ammonia is decomposed by the oxygen-

nated acid; the hydrogen of the alkali unites with the excess of oxygen contained in the acid, and forms water, which mingles with the acid; whilst the azot, the other constituent part of the ammonia, appears uncombined in the form of gas. The gas was found by Berthollet to be azotic, both by the common methods of examination, and by its forming nitrous acid when united with oxygen by means of the electric spark, in the method that Mr. Cavendish had discovered. The same decomposition takes place if the oxy-muriatic acid and the ammonia are used in form of gas. See *OXY-MURIATIC ACID*.

This theory of the decomposition of ammonia was also beautifully illustrated by the same ingenious chemist, in his accurate and original experiments on the nature and preparation of fulminating gold. These will be given more at length under the article *GOLD*; but it may be here mentioned that the fulminating compound is formed by precipitating a solution of gold in aqua regia by the volatile alkali. This precipitate consists of the metal, of oxygen which it acquires during solution in the acid, and of a part of the ammonia employed to separate it from its menstruum, which is retained by the metallic oxyd, and which gives it the property of exploding in a very gentle heat. M. Berthollet ventured to explode small and known quantities of this preparation in copper tubes, and found the products to be water and azotic gas and the oxyd of gold completely reduced. The ammonia therefore is here decomposed, its hydrogen produces water with the oxygen of the gold, and its azot is set at liberty in the form of gas. Some other of the metals which have a weak affinity for oxygen are reduced to a reguline state by means of the volatile alkali, which is also decomposed in the process. M. Berthollet also repeated Dr. Priestley's experiment of the analysis of ammoniacal gas by electricity, taking every possible precaution in order to ensure an accurate result; and the calculations deduced from it have been very generally acquiesced in, and confirmed by subsequent enquirers. For this purpose he passed a succession of electric sparks through 1.7 cubic inches of ammoniacal gas till it acquired its utmost degree of expansion, when it occupied 3.3 cubic inches, a degree intermediate between the results of Dr. Priestley and M. Van Marum. A certain quantity of this enlarged gas was then detonated with a superabundance of oxygen gas in Volta's eudiometer, whereby water was produced and the azotic gas of the ammonia remained unaltered. Then (assuming the quantity of oxygen entering into the composition of water to be to the hydrogen, as 74 to 145, according to the calculations of M. Monge, given in the Memoirs of the French Academy) M. Berthollet estimates the proportions of the constituent parts of ammonia to be 2.9, in *bulk*, of hydrogen, to 1.1 of azot, or, in *weight*, (assuming the hydrogen to be eleven times lighter than the azot) 150 grains of ammoniacal gas will contain 121 grains of azot, and 29 grains of hydrogen.—*Journal de Physique* for 1786.

The above are the principal facts which have been brought to prove the *decomposition* of ammonia. A number of others, equally important and curious, will throw light on the mode of its *formation* from the union of its constituent parts.

An accidental production of ammonia in circumstances where it had not been expected had frequently been remarked by various chemists. Dr. Priestley, in his numerous experiments on nitrous air, found by accident that when iron filings had been long kept in a jar, and moistened with a diluted solution of copper in the nitrous acid, a thick

saline red incrustation was formed, mixed with a green matter, which, when broken, had a strong smell of volatile alkali. Repeating the experiment he found that the same effect would be produced, though more slowly, by simply allowing iron to rust in nitrous air, when, after some weeks, the smell of volatile alkali plainly appeared. The nitrous gas likewise underwent a considerable change, being diminished about one-third, and then supporting combustion in a high degree, which last property was, however, lost by washing in water, and a large residuum of phlogisticated air was left.

A production of ammonia, in somewhat similar circumstances, is likewise particularly noticed by Mr. Haussman of Colmar. (*Journal de Physique* for 1787.) He relates, that on mixing nitrous gas with phlogisticated precipitate of iron, a large quantity of the gas is absorbed, leaving only a small residuum of phlogisticated air; and on adding caustic fixed alkali to the iron precipitate, a smell of volatile alkali is very perceptible, and a straw moistened with nitrous acid and held over the mixture also indicates the presence of ammonia by forming dense white fumes. Mr. Haussman distinguishes accurately between the phlogisticated and the dephlogisticated solutions of iron, the former being formed by dissolving the metal in acetic acid, or in the vitriolic without previous preparation; and the latter being a solution in vitriolic acid of iron which has been previously precipitated from a nitrous solution, and is therefore fully dephlogisticated, or, as is now said, in the highest state of oxygenation. The same chemist employed the solutions of iron in various states, and found, that wherever nitrous gas was absorbed by the iron, a certain quantity of ammonia is also produced, which, he also observes, probably remains in union with the vitriolic acid till it is displaced by caustic fixed alkali. The properties of this compound of nitrous gas and oxyd of iron will be examined more particularly under the article *EUDIOMETRY*, as it is intimately connected with this subject.

Still further light was thrown on the curious phenomenon of the production of ammonia, by some interesting experiments of Dr. Austin. (*Philosoph. Transact.* for 1788, vol. lxxviii.) The composition of ammonia having been fully ascertained by the experiments of Priestley, Berthollet and others, Dr. Austin attempted to produce the alkali by a direct union of its constituent parts. For this purpose he mixed inflammable and phlogisticated airs in different proportions, and added to them some of the acid airs in order to favour their combination, tried the effects of cold, of heat, of electricity; and lastly, he decomposed alkaline air, and endeavoured to reunite the identical parts, but in no instance could he succeed in forming ammonia from the constituent parts of this alkali, *when both were employed in a gaseous form*.

Hydrogen and azot, however, are certainly the constituent parts of ammonia, and their refusal to unite when in the form of gas led Dr. Austin to vary his experiments by mixing these substances together in such a manner that the hydrogen should be involved in an atmosphere of azotic gas just at the time when it was itself beginning to assume the gaseous form. This has with great propriety been termed the *nascent state* of a gas, and this experiment was suggested to Dr. Austin by another very striking production of ammonia from nitrous acid and tin, which we shall presently mention. He therefore inclosed in a glass tube some azotic or phlogisticated air, and along with it some iron filings, moistened with water, which last were known to yield inflammable air after standing together for some hours; and this air therefore in its nascent state, or at the

instant of its formation, was in full contact with the azotic gas. To detect the minutest quantity of ammonia he also inclosed in the tube some paper stained with the blue of the rind of the radish, which is turned to green by alkalis. In twenty-four hours he found the colour entirely green. Another test was also used to indicate the presence of ammonia, which was paper stained with a solution of nitrated copper; the green of which was, in a few days, converted to blue, the proper colour of a solution of copper in ammonia. Dr. Austin found nitrous air to effect a much more speedy production of ammonia when used instead of the azotic gas. Atmospheric air will also succeed, but requires a longer time than the azotic air, so that ammonia should always be formed whenever iron in contact with water rusts in the open air. In this formation of ammonia by the direct combination of its principles, it is necessary, as Dr. Austin observes, that the hydrogen should be only in the nascent state when it comes in contact with the azot, for if it is already in the form of gas it cannot be made to unite with the azot in any form so as to produce ammonia.

We may here remark, that this mode of effecting chemical union between bodies which, when uncombined, are only known in the gaseous form, (such as oxygen, hydrogen, and azot) by presenting one to the other when in the nascent state, should always be kept in mind in experiments of research, as it may be the means of very important discoveries in this difficult part of experimental chemistry. Mr. Kirwan, in his valuable experiments on hepatic air, observed the formation of volatile alkali when this air was mixed with nitrous gas. At the same time sulphur is deposited.

Another very striking experiment on the formation of ammonia, which is easily made and seldom fails of success, is the following. Take some powder, or filings of tin or zinc, pour on them some moderately dilute nitrous acid, which will act on them with great vehemence, and the disengagement of copious red fumes. After a short time stir into the mixture some quicklime or caustic alkali, and a very strong pungent smell of ammonia will be produced. In this case the ammonia is formed by the decomposition of the nitrous acid and the water, this ammonia instantly unites with a portion of the acid, forming nitrated ammonia, and the lime again decomposes this ammoniacal salt by simple affinity, and by displacing the alkali from its union with the acid, causes it to assume the gaseous form and to become evident to the senses.

Before we quit the subject of the composition of ammonia, we shall make a few observations on the decomposition of nitrous gas and nitric acid in the experiments above related, whereby the volatile alkali is produced. In the simpler methods of forming ammonia, such as in Dr. Austin's experiments, the union of the nascent hydrogen with azotic gas, the affinities which operate in forming the alkali, may be supposed to be tolerably simple. But when the nitric acid, or nitrous gas are used, the affinities appear to be extremely complex, and perhaps hardly made out with much certainty. It should be noted, however, that, along with the production of ammonia, there appears constantly a proportionate quantity of that singular gas discovered by Dr. Priestley, and called by him dephlogisticated nitrous air; and of late denominated *nitrous oxyd* by Mr. Davy, to whose highly ingenious "*Researches*" we are indebted for much important addition to this curious and difficult part of chemistry. It is a striking property of the nitrous oxyd to support combustion in a very eminent manner, and very similar to oxygen gas, although it contains a less proportion of oxygen, and more azot than *nitrous gas*,

which is unfit for combustion. This resemblance to oxygen gas in the nitrous oxyd has misled some chemists in the nature of the air left after the formation of ammonia from nitrous gas and nascent hydrogen, who have supposed a production of oxygen, and have been obliged to account for it accordingly. To explain the changes that take place with moistened iron filings, confined in an atmosphere of nitrous gas, we must observe, that the new compounds, which we know are formed out of these materials, are ammonia, consisting of azot and hydrogen, and nitrous oxyd, composed of much azot and little oxygen. The iron likewise is rusted or oxygenated. The source of the hydrogen in the new products may be supposed to be some of the water decomposed, from which the metal, in rusting, has abstracted its other constituent part, the oxygen. The only source of the azot (allowed by the antiphlogistic theory) is the nitrous gas, which is composed merely of this principle, and of oxygen. But if merely a portion of the azot of the nitrous gas was abstracted from it, the remainder, by losing azot, would be a substance containing (proportionally) more oxygen than nitrous gas; whereas, the nitrous oxyd, which is this remainder, contains less. There must, therefore, be an additional method of getting rid of this excess of oxygen, in order to produce a satisfactory explanation; and the only substance that offers is the hydrogen of the water decomposed by the metal, which may be supposed to unite with enough of the oxygen of the nitrous gas to reduce it to the state of nitrous oxyd. Thus then, according to this hypothesis, the metal decomposes the water, the hydrogen set at liberty by this decomposition unites with a small part of the azot of the nitrous gas to form ammonia, and with a greater part of its oxygen, to form water, and the residue of the nitrous gas is in that proportion and mixture which constitutes nitrous oxyd.

We shall not pursue this subject farther at present, as it will apply to all the cases of the production of ammonia by nitrous acid, and it may, perhaps, be thought too hypothetical to be further insisted on, though there are many similar examples to be met with, of very extensive and complicated affinities being set in motion by a single disturbance of the quiescent attractions of the constituent parts of any of the substances contained in the mixture.

Having now enumerated some of the leading facts by which the composition of the volatile alkali has been established, we shall proceed to mention some of the mixtures of ammonia with various chemical agents. It may be observed that though the uncombined volatile alkali is in the form of gas when pure, all its combinations are either solid or liquid, and hence every substance added to the ammoniacal gas causes an absorption of it where any chemical action takes place. However, the tendency to the æriform state is so far retained by ammonia in all its combinations as to render them volatile, and to weaken its adhesion for them, whenever the temperature is raised to a certain degree. The force of affinity which ammonia exercises is therefore remarkably weakened by heat, where the substance to which it is united is naturally fixed in the fire, and many of the ammoniacal compounds at a high temperature are totally decomposed, and entirely new products result from the operation.

No union takes place by any simple mixture of ammonia with oxygen, hydrogen, or azotic gases. Under particular circumstances, and by the agency of complicated affinities, these substances may however be mutually decomposed, and new compounds produced. Thus, ammoniacal gas passed over heated oxyd of manganese forms NITROUS ACID, as discovered by the ingenious experiments of Dr. Milner.

Ammonia unites with all the acids with very great ease

and rapidity, forming with them very easily soluble salts. These will be particularly mentioned under the respective acids, but some of their properties may here be mentioned. The union of alkaline air with the acid gases, as discovered by Dr. Priestley, forms some of the most striking and beautiful experiments which chemistry furnishes. If ammoniacal gas is passed up into a jar containing carbonic acid there is a thick white fume immediately produced, the two gases by uniting lose their gaseous form, so that there is a complete vacuum suddenly made in the jar, causing the mercury over which it is confined to rise and fill it entirely, a sensible quantity of heat is given out, and a number of minute crystals of carbonated ammonia lining the inside of the jar, is the product of the mixture.

With the muriatic acid gas the appearances are exactly similar, only the white fume is still more dense and copious, the heat greater, and the union more rapid. Crystalline feathers of MURIATED ammonia are the result, and this furnishes one of the most striking instances of alteration in form, and in sensible properties, which two bodies may undergo by chemical affinity; for each of the ingredients when separate are in the state of an invisible gas with a highly pungent smell, and, when united, a scentless solid salt is the product. In making this beautiful experiment both the gases should be confined over mercury; and, on account of the much superior specific gravity of the acid gas over the alkaline, if the former is thrown into a jar of the latter, the white cloud will form slowly, beginning from the point of contact of the gases; but if the alkali be added to the acid gas, it rises through it immediately, and the combination takes place with great rapidity.

The nitrous acid unites with ammonia with great ease, and with the production of white fumes when the two substances are gaseous. The resulting salt NITRAT of ammonia possesses very interesting properties, which will be mentioned under that article.

It may be of use to know that the presence of ammoniacal gas, where it cannot conveniently be detected by the smell, will be readily shewn by holding a piece of glass rod or any other substance wetted with nitrous or muriatic acid, over the part where ammonia is suspected, when thick white fumes will be seen to form around the acid.

Phosphorus will not unite with ammonia at a low temperature. In a red heat the alkali is decomposed, and phosphorated hydrogen, and azotic gas are produced.

With sulphur, ammonia unites with some difficulty, forming the SULPHURET of ammonia, or *Boyle's fuming liquor*.

Charcoal and the volatile alkali do not unite in a moderate heat, but at high temperatures the alkali is decomposed, and, by particular management, that singular substance, the PRUSSIC acid, may be formed.

The affinity of ammonia for the different acids is much weaker than that of the other alkalies, and several of the earths. In several solutions of earths or metals in acids, where the affinity of ammonia for the acid is only in a small degree greater than of the earth or metal, only a part of the substance dissolved is precipitated by the addition of this alkali, and the solution retains the remainder, united with the ammonia, forming together an ammoniacal triple salt. Thus if to a solution of magnesia ammonia is added, part only of the earth is precipitated, and the remaining solution is an ammoniac-magnesian salt. Also the affinities of ammonia are much weakened by heat, owing to the great tendency to volatilization which the alkali possesses.

Ammonia has a very striking property of reducing to the metallic state (either entirely or partially) the oxyds of the several metals. This is performed, as we have already men-

tioned in the instance of fulminating gold, by a decomposition of the alkali, its hydrogen uniting with the oxygen of the metallic oxyd to form water, and its azot appearing uncombined in the form of gas. Thus, as M. Fourcroy has observed, (*An. Chym. tom. 2 & 6.*) if the black oxyd of manganese is moistened with liquid ammonia, and gentle heat be applied, the oxyd passes to the state of the white oxyd, (which is nearer the metallic state) and an effervescence with disengagement of azotic gas takes place. The red oxyd of mercury, treated in a similar manner, gives the same results, and the metal is left in the state of a black powder, which simple exposure to light and air will convert to globules of running mercury. This affords a ready way of cleaning the surface of mercury that has been tarnished and oxydated by acid vapours.

Some of the most difficultly reducible metals, such as manganese or tungsten, are on this account best prepared for reduction by being previously united with ammonia.

The volatile alkali may be made to unite with oils, so as to form ammoniacal soaps; but this combination is less perfect than the fixed alkaline soaps, on account of the impossibility of applying heat to promote union without driving off much of the alkali in the form of gas. The volatile oils are equally soluble in ammonia with the fixed, an example of which is that union of oil of amber with ammonia, which forms EAU DE LUCE.

A great variety of vegetable and animal substances are dissolved or decomposed by this alkali, which renders it of the highest importance in the ANALYSIS of animal and vegetable matters.

The uses of the volatile alkali are numerous and important.

To the chemist, as a re-agent of very extensive utility, it is an indispensable requisite, as there is hardly a single analysis of mineral, vegetable, or animal matter performed (where at all complicated) in which ammonia is not largely employed.

In medicine this alkali is highly valuable, on account of its strong and diffusible stimulant properties. When taken internally, its first effect is generally upon the throat and fauces, owing to its partial volatilization by the heat of the mouth. Every one is familiar with its use in relieving faintings and sickness when snuffed up the nostrils, though from the great acrimony of the caustic ammonia, the milder form of the carbonated ammonia, or *sal volatile* is generally preferred. The strong and sudden stimulus which it gives to the system, when applied to the nostrils, renders it also one of the most powerful applications in many of the more serious suspensions of the vital powers. The pure liquid ammonia is much too acrid to be used by itself, even as an external application, but when mixed with oil it forms a very useful liniment for strains, indolent swellings, and any case in which a powerful stimulant is required. Simple agitation with oil will unite the two liquors into an uniform milky saponaceous liquid, in which the sensible properties of the alkali are only blunted and not neutralized. A peculiar use of the liquid ammonia largely diluted with water, and taken internally, is in checking the sudden and dreadful effects produced by the bite of venomous serpents.

Priestley on Air.—*Journal de Physique* for 1785, 6, and 7.
—*Philos. Transact.* for 1788.—*Anal. de Chimie*, tom. ii. & vi.
—*Davy's Researches*, &c. &c.

AMMONIA, in *Mythology*, an appellation of Juno, to whom the Eleans sacrificed, alluding, perhaps, to Jupiter Ammon.

Anchor

ANCHOR, ANCHORA, from the Latin *ancora*, or *anchora*, of the Greek *αἰκυρα*, which comes from *αἰκυλος*, *incurvus*, *crooked*, a large, strong, and heavy piece of iron, composed of a long shank, having at one end a ring to which the cable is fastened, and at the other two arms or flukes, with barbs or edges on each side, and used for fixing and retaining a vessel in a harbor, road, or river.

The anchor is an instrument of very ancient use. Pliny (lib. viii. c. ult.) ascribes the invention of it to the Tuscans; and Pausanias (Attic, lib. i. c. 4. p. 12.) refers it to Midas, the son of Gordius, who built the city Ancyra. The most ancient anchors were of stone, and sometimes of wood, to which a quantity of lead was attached; in some places they used baskets full of stones, and sacks filled with sand. These were suspended by cords, and their weight regulated the course of the ship. Afterwards anchors were constructed of iron, and furnished with teeth or flukes, which fastening to the bottom of the sea, kept the ship immovable; hence *οδοντες*, *teeth*, are used for anchors. The first anchors had only a tooth or fluke, on one side; and on this account they were denominated *ἡμιτομοι*; the contrivance was completed,

according to Pliny, (*ubi supra*,) by Eupalamus, who made them fluked both ways, or according to Strabo (lib. vii. ex Ephor, tom. p. 464.) the second tooth or fluke was added by Anacharsis, the Scythian. The anchors with two teeth were called *αμφιβολοι*, or *αμφιτομοι*. Every ship had several anchors, the largest of which was called *ιερὰ*, *sacred*, and was never used but in extreme danger; whence the phrase "*sacram anchoram solvere*," is proverbially applied to such as are reduced to their last refuge.

All anchors have now two arms; not but they might still be used with only one arm, which structure would have this advantage, that they would be lighter, and yet in fine weather would hold equally firm with the double kind. The reason of having two arms is, that the anchor may always take, in order to which it is necessary that it be very heavy; besides, that anchors with a single arm would require more preparation for service.

Travellers tell us of people who make use of wooden anchors in their navigation. The inhabitants of the island of Ceylon, in lieu of anchors, use large round stones, and in

in other places, their anchors are a kind of wooden machines, loaded with stones. Sometimes bags of sand have been made use of, but these chiefly obtained in rocky places, where anchors would not take hold. In England, France, and Holland, anchors are made of forged iron; but in Spain, they are sometimes made of copper, and likewise in several parts of the South sea.

The anchors now made are so contrived as to sink into the ground as soon as they reach it, and to hold a great strain before they can be loosened or dislodged from their station. The parts of which an anchor is composed are the ring, into which the cable is fastened, the beam, or shank, which is the longest part of the anchor, the two arms, at the end of which are the two flukes or flukes, by some called the palms, which with their barbs fasten into the ground, and the stock, which is a long piece of wood, fastened across the beam, near the ring, and serving to guide the flukes in a direction perpendicular to the surface of the ground; so that one of them sinks into it by its own weight, as soon as it falls, and is still preserved steadily in that position by the stock, which, together with the shank, lies flat on the bottom. In this situation it must necessarily sustain a great effort before it can be dragged through the earth horizontally. This, indeed, can only be effected by the wind or tide, or by both of them; the effect of which is sometimes increased by the turbulency of the sea, and acts upon the ship so as to stretch the cable to its utmost tension, and may thus dislodge the anchor from its bed, especially if the ground be soft, and oozy, or rocky. When the anchor is thus displaced, it is said, in the sea-jargon, "to come home."

The several parts of the anchor, above enumerated, bear the following proportions. The length of the arm, from the inside of the throat to the bill, is the distance marked on the shank for the trend, taken from the inside of the throat; and three times that is the length of the shank from the tip of the crown; and the shank, from the tip of the crown to the centre of the ring, is the length of the iron stock; when made, the two arms, from the inside of the throat to the extremity of the bill, should form an arc of a circle, containing 120 degrees. See *Plate XI. ships*.

Of anchors there are the sheet, best bower, small bower, and spare anchor. These do not vary in form or weight from each other, in the navy. Stream and kedge anchors are smaller, and grapnels are only for boats. Ships of 110, 100, 98, and 90 guns, have seven anchors; from 80 to 20 guns inclusive, six anchors; ships of 300 tons, and sloops have five; and brigs and cutters three anchors.

ANCHORS, method of making. The goodness of the anchor is a point of great importance; the safety and conservation of the vessel depending principally upon it. The shank, arms, and flukes, are first forged separately; then the hole is made at one end of the shank for the ring, which being also previously forged, is put into the hole of the shank, and the two ends shut together. After which the arms are shut to the shank, one after the other, and the anchor is finished.

The shank is made of many long bars of the best tough iron, well wrought together; and great care should be taken, that the iron be neither too soft nor too brittle; the latter rendering it liable to break, and the former to straiten. The number of bars sufficient to make the shank of the intended size, must be regulated by experience. Several parts of the anchor are governed by the size of the trend, which is marked on the shank at the same distance from the inside of the throat as the arm measures from the inside of the

throat to the extremity of the bill. The shank is rounded to the square of the upper part, and is there called the small round, being the smallest part. The two sides in the direction of the arms are flatted surfaces, about an inch less than the trend, in large anchors, and something less in smaller ones. The squared part is of the same size as at the trend each way, and hanches into the small round, one-sixth of the length of the shank. The hole, or eye, for the ring, is punched through the square part, or the flatted side, once and a half the thickness of the ring, from the upper extremity of the shank, which has its corners flatted or diamonded, on the same sides, nearly in the middle. Between the hole for the ring and lower part of the square are too small prominences, raised across from the solid, called nuts, for securing the stock in its place. At the lower part of the shank is left a scarf, or flatted surface, with a shoulder on each side, for shutting on the arms.

In making every part of an anchor the nicest attention should be observed, as to its being smooth, fair, and even; and that the edges and angles are preserved straight in their direction, as well-made anchors should possess beauty as well as strength. The ring, being previously forged, is put through the fore-mentioned hole in the shank, and the two ends are well shut together. The arms are made of shorter bars than the shank, but as good in quality, and as well put together; they are rounded and flatted on the different sides, to resemble the shank, and are of the same size as the shank, at the throat and small round. The rounding part is continued to the palm, which is nearly in the middle of the arm; from thence it is made with a square tapering to the bill on the flatted side; and, on the inner rounded side, is made a square seat for shutting on the palm, that the palm, when shut on, should project its thickness at the base or inner part, the outer part making a straight surface with the peak or bill. The back or outer side of the arm is made straight from the rounded part, or hanch, to the snape, and there kept to half the substance of the inner part. The snape resembles the bill of a duck, and is one-third the breadth of the palm in length. The thickness of the ring is to be half the diameter of the small round. The diameter of the ring, including the thickness, reaches from the hole in the upper part of the shank to the hanch of the small round. The inner part of the arm is mostly made straight, from the bill to the throat; and it is thought stronger for having a small angle in its length, inclining to the shank. Shanks taper in their length, one and one-half inch in small anchors to three inches in large, keeping their proper size at the trend; and three-fourths of an inch to two inches in the flatted way. The arm in its length inclines to the shank, and forms a small angle, the touch or point thereof being in the middle. The throat-end of the arm is scarfed, or flatted, to answer the scarf in the shank, to which the two arms are united (after the palms are shut on) in the firmest manner possible; and it is elevated above the horizontal plane, or inclined to the shank, that each arm may spread at the peak or bill. The length of the arm, from the inside of the throat to the extremity of its bill, is then taken, and that length from the inside of the throat is set upon the shank, and called the trend; from the trend to the bill is formed an angle of about 60 degrees. The palms, or flukes, are two thick plates of iron, made of various pieces, well wrought together, in the form of an isosceles triangle; one and one-half inch to one and one-fourth inch longer than the breadth of the base, and curve about as much in their sides. The base or lower part, is to be straight; the inner flat surface curves a little in the breadth, but is straight

lengthways; the palms, being finished thus far, are, lastly shut firmly into the inner side of the arm, in the seat before mentioned, the base inclining inwards.

The stock is composed of two long beams of oak, strongly bolted and tree-nailed together, and secured with four strong iron hoops, two on each side of the middle, and one near each end. It is fixed on the upper end of the shank, transversely with the flukes or palms; and the nuts are let into the middle of the stock. The length of the stock is the length of the shank and half the diameter of the ring; the depth and thickness in the middle are as many inches as the stock is feet in length. The ends are to be kept square, half the depth or thickness in the middle. The upper side next the ring is always kept straight, as is the lower side half the depth on each side the middle; and thence it tapers to each end in the above proportion. It is necessary to leave an opening in the middle of one and one-half inch, between the two pieces, that the hoops may be driven nearer the middle, in case the stock should shrink. The making of anchors is a very laborious business, and has been much facilitated by the invention of two machines, called the *HERCULES* and the *MONKEY*.

Proof is made of anchors, by raising them to a great height, and then letting them fall again on a kind of iron block placed across for the purpose. To try whether the flukes will turn to the bottom, and take hold of the ground, they place the anchor on an even surface, with the end of one of the flukes, and one of the ends of the stock resting on the surface; in case the anchor turns, and the point of the fluke rises upwards, the anchor is good.

For the proportions of anchors according to Manwaring, the shank is to be thrice the length of one of the flukes, and half the length of the beam. According to Aubin, the length of the anchor is to be four-tenths of the greatest breadth of the ship; so that the shank, *e. gr.* of an anchor in a vessel thirty feet wide, is to be twelve feet long. When the shank is, for instance, eight feet long, the two arms are to be seven feet long, measuring them according to their curvity. As to the degree of curvity given the arms, there is no rule for it; the workmen are here left to their own discretion.

Aubin, in his *Marine Dictionary*, gives a table from a Flemish writer, wherein the lengths of the shanks of anchors for vessels of all widths, is computed, as well as the weights of the anchors, from a vessel eight feet wide within, which requires an anchor three and one-half feet long, weighing thirty-three pounds, to a vessel forty-five feet wide, which demands an anchor eighteen feet long, and weighing 5832 pounds. He likewise observes, that the anchor of a large heavy vessel is smaller, in proportion, than that of a lesser and lighter one. The reason he gives is, that though the sea employs an equal force against a small vessel as against a great one, supposing the extent of wood upon which the water acts to be equal in both, yet the little vessel, by reason of its superior lightness, does not make so much resistance as the greater; the defect whereof must be supplied by the weight of the anchor.

From these and other hydrostatic principles, the following table has been formed; wherein is shewn, by means of the ship's breadth within, how many feet the beam or shank ought to be long, giving it $\frac{1}{4}$ or $\frac{2}{3}$ of the ship's breadth within; by which proportion may be regulated the length of the other parts of the anchor. In this table is represented likewise the weight an anchor ought to be for a ship from eight feet broad to 45, increasing by one foot's breadth; supposing that all anchors are similar, or that their weights are as the cubes of the lengths of the shanks.

Breadth of the Vessel	Feet.	Length of the Anchor	Feet.	Weight	Pounds.
	8		3 $\frac{1}{2}$		33
	9		3 $\frac{3}{4}$		47
	10		4		64
	11		4 $\frac{1}{4}$		84
	12		4 $\frac{1}{2}$		110
	13		5		140
	14		5 $\frac{1}{4}$		175
	15		5 $\frac{1}{2}$		216
	16		6		262
	17		6 $\frac{1}{4}$		314
	18		6 $\frac{1}{2}$		373
	19		7		439
	20		7 $\frac{1}{4}$		512
	21		7 $\frac{1}{2}$		592
	22		8		681
	23		8 $\frac{1}{4}$		778
	24		8 $\frac{1}{2}$		884
	25		9		1000
	26		9 $\frac{1}{4}$		1124
	27		9 $\frac{1}{2}$		1259
	28		10		1405
	29		10 $\frac{1}{4}$		1562
	30		10 $\frac{1}{2}$		1728
	31		11		1906
	32		11 $\frac{1}{4}$		2097
	33		11 $\frac{1}{2}$		2300
	34		12		2515
	35		12 $\frac{1}{4}$		2742
	36		12 $\frac{1}{2}$		2986
	37		13		3242
	38		13 $\frac{1}{4}$		3512
	39		13 $\frac{1}{2}$		3796
	40		14		4096
	41		14 $\frac{1}{4}$		4426
	42		14 $\frac{1}{2}$		4742
	43		15		5088
	44		15 $\frac{1}{4}$		5451
	45		15 $\frac{1}{2}$		5832

M. Bouguer directs to take the length of the shank in inches, and to divide the cube of it by 1160 for the weight. The reason is obvious; because the quotient of the cube of 201 inches, which is the length of an anchor weighing 7000lb. divided by the weight is 1160. and therefore by the rule of three, this will be a common divisor for the cube of any length, and a single operation will suffice. The same author, in his *Traite de Navire*, gives the following dimensions of the several parts of an anchor. The two arms generally form the arch of a circle, whose centre is three eighths of the shank from the vertex, or point where it is fixed, to the shank; and each arm is equal to the same length or the radius; so that the two arms together make an arch of 120 degrees: the flukes are half the length of the arms, and their breadths two-fifths of the said length. With respect to the thickness, the circumference at the throat, or vertex of the shank, is generally made about the fifth part of its length, and the small end two thirds of the throat, the small end of the arms of the flukes, three fourths of the circumference of the shank at the throat. These dimensions should be bigger, when the iron is of a bad quality, especially if cast iron is used instead of forged iron.

The Number of Anchors allowed each Ship in the Royal Navy, with their Weight and Value.

S. Stands for Stream, K. for Kedge.

No.	110 & 130 GUNS.	VALUE.	No.	15 and 20 GUNS.	VALUE.	No.	30 and 36 GUNS.	VALUE.	No.	Smaller 74 GUNS.	VALUE.	No.	64 GUNS.	VALUE.
	Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.	
S. 1	81 0	121 5 0	S. 1	73 0	100 3 15	S. 1	71 0	78 1 0	S. 1	67 0	67 0 0	S. 1	57 0	50 2 2
K. 1	21 0	32 11	K. 1	18 0	27 0	K. 1	17 2	26 0	K. 1	16 0	24 0	K. 1	15 0	22 10
	10 2	15 15		9 0	13 10		8 2	12 10		8 0	12 0		7 2	11 0
No.	65 GUNS.	VALUE.	No.	50 GUNS.	VALUE.	No.	44 and 46 GUNS.	VALUE.	No.	36 GUNS.	VALUE.	No.	32 GUNS.	VALUE.
	Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.	
S. 1	53 0	43 7 17	S. 1	49 0	38 2 4	S. 1	40 0	27 2 0	S. 1	39 0	24 0 16	S. 1	33 0	21 0 4
K. 1	12 0	18 0	K. 1	11 0	16 10	K. 1	10 0	15 0	K. 1	9 0	13 10	K. 1	8 1	12 5
	6 0	9 0		5 2	8 0		5 0	7 10		4 2	6 10		4 0	6 0
No.	28 GUNS.	VALUE.	No.	14 and 20 GUNS.	VALUE.	No.	14 GUNS 300 TONS.	VALUE.	No.	SLOOP, 200 TONS.	VALUE.	No.	BRIGS, 200 TONS.	VALUE.
	Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.			Cwt. Qr. l. s.	
S. 1	31 0	19 8 8	S. 1	23 3	18 0 16	S. 1	20 0	93 0	S. 1	15 0	67 10	S. 1	12 0	54 0
K. 1	8 0	12 0	K. 1	7 2	11 0	K. 1	7 0	10 10	K. 1	6 0	9 0		CUTTER	
	4 0	6 0		3 2	5 0		3 2	5 0		3 0	4 10		10 0	45 0

See Murray's Treatise on Ship-building, &c. Elements and Practice of Rigging and Seamanship, 4to. 1794, p. 77—82.

The distinctions of anchors are taken from their use, and the proportions they bear in the ship, where they are employed; for that which in one ship would be called but a *kedge*, or *kedge-ANCHOR*, in a lesser would be a *sheet-ANCHOR*.

ANCHOR, kedge, is the smallest, which, by reason of its lightness, is first to stop the ship in *kedging* a river.

This is what the Dutch sailors call *werp-ANCHOR*, the French *ancre a touer*. It ought to weigh 450 pounds.

The *grapnel* is an anchor for a small ship or boat. See *KEDGE* and *GRAPNEL*.

ANCHOR, stream, is a small anchor fastened to a stream-cable, wherewith to ride in rivers, and gentle streams, and to stop a tide withal in fair weather.

ANCHOR, sheet, or *sheet*, is the biggest and strongest, being that which the seamen call their last hope; never to be used but in great extremity.

This is what the Romans call *anchora sacra*; the Dutch *plegt-anker*, and *stop-anker*; the French *maitresse-ancre*, or *grand ancre*.

The other anchors are called by the name of the first, second, and third anchor; by any of which the ship may ride in any seasonable weather, sea-gate, or tide.—These are something bigger one than another, and usually when they fail in any streights, or are near a port, they carry two of these at their bow; in which respect they are also called by the name of first and second bowers.

ANCHOR, second, called by the Dutch *borg-anker*, or *dangelyks-anker*, is that ordinarily made use of.

ANCHOR, cross, called by the Dutch *tuy-anker*, or *vertuy-anker*, and by the French *ancre d'affourche*, is a middling anchor thrown across or opposite to another.—This ought to weigh 1500 pounds, or nearly as much as the second anchor.

ANCHOR, floating, is a simple machine, which is made to dive beneath the swell of the sea, and retain the vessel where there may be no other anchorage. It consists of two flat bars of iron, each in length half the breadth of the

midship beam of the vessel for which it is used, and rivetted together in the middle by an iron saucer-headed bolt, clenched at its point, that they may be swung parallel to each other for easy stowage. At each end of the bars is a hole for a rope, or swifter to pass through, which must be hove tight to extend the bars at right angles. To this swifter is marked a double or four-fold canvas cloth, so as to be on that side of the iron bars nearest the vessel when used. In each bar are two holes, at equal distances from the centre, and to these holes the ends of two pieces of rope are fastened; the ropes are seized together in the middle so as to form a crow-foot, having an eye in the centre, which is well sewed with spun-yarn, and to this is bent, when the anchor is used, a cable or hawser, by which it is made to sink and incline in the water. See *Plate XI. Ships*. In the end of one of the bars is fitted an iron ring to which a buoy is made fast, by a rope about 12 fathoms long, to prevent the anchor from sinking to the bottom. When it is thrown over-board, the cable and a rope made fast to the head of a buoy, are carried away sufficiently to ride the vessel. To get it on board, haul upon the buoy-top, which will bring it to the water's surface so as to be easily drawn to the vessel. Have the mizen stay-sail ready to hoist, so as to keep the vessel to the wind, till the anchor is hauled on board.

A *floating* or *swimming anchor* will serve to prevent a ship, in a storm, from driving to leeward in deep water. Dr. Franklin suggests that an anchor, effectual for this purpose, ought to have the following properties. It should have a surface so large as being at the end of a hawser in the water, and placed perpendicularly, should hold so much of it, as to bring the ship's head to the wind, in which situation the wind has least power to drive her. It should be able by its resistance to prevent the ship's receiving way. It should be capable of being situated below the heave of the sea, but not below the undertow. It should not take up too much room in the ship. It should be easily thrown out, and put into its proper situation. And lastly, it should be easy to take in again, and stow away. Many contrivances have been

suggested for this purpose. One for a large ship might have a stem of wood 25 feet long and four inches square, with four boards, 18, 16, 14, and 12 feet in length, and one foot wide, with a hole in the middle of each, about four inches square, so that it might be occasionally slipped upon the stem at right angles with it; and when these boards are fixed at the distance of four feet from each other, the anchor would have the appearance of the old mathematical instrument called the forestaff. This thrown into the sea, and held by a hawser veered out to some length, would bring a vessel up and prevent her driving, and when taken in it might be stowed away by separating the boards from the stem. Such a swimming anchor would have some good effect, but as it lies on the

surface of the sea, it is liable to be hove forward by every wave, and then only give so much leave for the ship to drive. Dr. Franklin has proposed two machines for this purpose, which he conceives, would be more effectual and more manageable. The first of these is to be formed, and used in the water on almost the same principles, with those of a paper kite in the air; only that as the paper kite rises in the air, this is to descend in the water; and its dimensions must be different for ships of different sizes. The other machine is to be made more in the form of an umbrella. See a particular description of both these machines, with figures, in the Transactions of the American Philosophical Society, vol. ii. p. 311—314.

Anemometer & Anemoscope

ANEMOMETER, compounded of *ἀνέμος*, *wind*, and *μέτρον*, *measure*, in *Mechanics*, a machine wherewith to measure the force and velocity of the wind. The anemometer is variously contrived. The first of the kind seems to have been invented by Wolfius in 1708, and first published in his "*Aerometry*" in 1709, and also in the "*Acta Eruditorum*" of the same year; afterwards in his "*Mathematical Dictionary*," and also in his *Elementa Matheseos*," vol. ii. p. 319. In the *Philosophical Transactions* we have one described, in which the wind being supposed to blow directly against a flat side or board, which moves along the graduated limb of a quadrant, the number of degrees it advances shews the comparative force of the wind.

This machine is moved by means of sails, A, B, C, K, (*Plate IX. Pneumatics, fig. 69.*) like those of a wind mill, which raise a weight L, that, still the higher it goes, receding farther from the centre of motion, by sliding along a hollow arm K M, fitted on to the axis of the sails, becomes heavier and heavier, and presses more and more on the arm, till being a counterpoise to the force of the wind on the sails, it stops the motion thereof. An index then, M N, fitted upon the same axis at right angles with the arm, by its rising or falling, points out the strength of the wind, on a plane divided like a dial-plate into degrees.

It is objected to this machine, however, that it requires a considerable wind to make it work. Leutmannus has contrived another, the sails of which are horizontal, and are more easily driven about, and will turn what way soever the wind blows.

In the *Philosophical Transactions* for the year 1766, Mr. A. Brice describes a method which has been successfully practised by himself, of measuring the velocity of the wind by means of that of the shadow of clouds passing over the surface of the earth.

Mr. d'Ons en Bray invented a new anemometer, which of itself expresses on paper not only the several winds that have blown during the space of twenty-four hours, and at what hour each began and ended, but also the different strength and velocities of each. Vide *Mem. Acad. Scienc. an. 1734*, p. 169. For other instruments of this kind, and their use, see *WIND-GAGE*.

ANEMOSCOPE, derived from *ἀνέμος*, *wind*, and *σκοπεῖν*, *I consider*, is sometimes used for a machine invented to foretel the changes of the wind. For this purpose it should consist of an index moving about a circular plate, like the

dial of a clock, on which the 32 points of the compass are drawn instead of the hours. The index, pointing to the divisions in the dial, is turned by an horizontal axis, having a handle-head at its outward extremity. This handle-head is moved by a cog-wheel on a perpendicular axis; on the top of which is fixed a vane, that moves with the course of the wind, and gives motion to the whole machine. The whole contrivance is very simple, and nothing is required in the construction, but that the number of cogs in the wheel and rounds in the trundle-head be equal; because it is necessary, that when the vane moves entirely round, the index of the dial should also make a complete revolution. An anemoscope of this kind is placed in one of the turrets of the Queen's palace. An account of an anemoscope contrived by Mr. Pickering, may be seen in the *Phil. Trans.* vol. xliii. pl. II. p. 9; and another described by Mr. Martin, in his *Philos. Britan.*, vol. ii. p. 211. See *ANEMOMETER* and *WIND GAGE*.

It has been observed, that hygrosopes made of cat's-gut, &c. prove very good anemoscopes; seldom failing, by the turning of the index about, to foretel the shifting of the wind.

The anemoscope used by the ancients seems, by Vitruvius's description of it, to have been intended rather to shew which way the wind actually blew, than to foretel into which quarter it would change.

Otto de Gueric also gave the title anemoscope to a machine invented by him, to foretel the change of the weather, as to fair and rain. It consisted of a wooden little man, who rose and fell in a glass tube, as the atmosphere was more or less heavy.—Accordingly, M. Comiers has shewn, that this anemoscope was only an application of the common *BAROMETER*. See *WIND*.

The anemoscope of Væroe is famous. It is made of the bird *lunde*, whose feathers are picked, the skin stripped off, *viscera* taken out, and the skin in this state drawn a-new over the bones; this being hung up in the chimney, is said always to direct its bill to the point from whence the wind is like to blow. *Ephem. Acad. N. C. Dec. 3. An. 9. App. 245.*

Antimony

ANTIMONY, Στιμμος, Στιμμος γυναιχισιον, Gr. *Sibium Jarbason*, Lat. *Spießglas*, *Spießglanz*, Germ. *Spießglas*, Swed. *Spießglas*, Dan. *Pisgotz*, Hung. *Antimoine*, Fr. *Antimonio*, Ital. *Antimonja*, Russ. *Proteus*, *leo ruber*, *plumbum nigrum*, *balneum regis*, *lupus metallorum*, Alchem.

Antimony is a brittle metal, of a brilliant white colour; fusible at a moderate red heat; and at a higher temperature, with access of air, it exhales a white inodorous vapour. It is soluble in nitro-muriatic acid, and precipitable from its solution of a white colour by distilled water, and of a deep brick-red by sulphuret of ammonia (volatile liver of sulphur.)

§ I. Ores of Antimony.

The antimonial ores have not as yet been analysed with sufficient accuracy to clear up all doubts as to the nature of their contents; an arrangement of them must, therefore, as yet principally depend on their external characters. We shall follow the example of Weidenmann, Emmerling, &c. in dividing them into several species, though probably the whole may be reduced to the native, the sulphurated, and the oxydated.

Sp. I. Native antimony. *Gediegen spießglas*, Germ. *Antimonium nativum*, Werner. *Antimoine natif*, & *A. blanche ou arsenicale*, Delisle, Haüy, and Born.

Has a light tin-white colour, with an occasional shade of yellow. Occurs massive, disseminated, or kidney-shaped. Is internally of a brilliant metallic lustre. Its fracture is either straight or curved foliated. The fragments are usually large or small grained; seldom conchoidal. It is soft, approaching to half hard, and of considerable specific gravity.

It melts with ease on charcoal before the blowpipe, exhaling a white arsenical fume, and readily amalgamates with mercury.

By the analysis of Mongez the younger, it appears to be a native alloy of antimony and arsenic, in the proportion of about 96 of the former to 4 of the latter.

Native antimony is a mineral of very rare occurrence; it was first found in 1748, by Schwab, in the silver mines of Sahla in Sweden, with a gangue of calcareous spar; and has since been detected by Sage imbedded in quartz in the mines of Allemont in Dauphiné.

Sp. II. Sulphurated A.—Grey antimonial ore. *Graues glaserz*, Germ. *Mine d'Antimoine grise ou sulfureuse*, Delisle. *Antimoine sulfuré*, Haüy.

Of this ore there are three varieties, the compact, foliated, and striated.

Var. 1. Compact. *Dichtes graues spießglaserz*, Germ. *An-*

timonium mineralizatum griseum densum, Werner.

The colour of this is lead-grey, passing into steel-grey, and tarnishes blue or purple on exposure to the air. It occurs massive or disseminated. Is of a metallic lustre, shining or little shining. Its fracture is small-grained uneven. It flies, when broken, into irregular blunt-cornered fragments. Is soft, gives a bright metallic streak, and is of considerable specific gravity.

It melts with great ease before the blowpipe, and burns with a blue flame, exhaling a copious white sulphureous vapour.

It is the scarcest of the sulphurated antimonial ores, and is found principally with quartz and spathose iron ore at Braunsdorf in Saxony, Goldkronach in Bayreuth, Auvergne in France, and Majurka in Hungary.

Var. 2. Foliated. *Blättriges graues spießglaserz*, Germ. *Antim. mineraliz. griseum lamellosum*, Werner.

This differs from the former variety in the following particulars. Colour, light steel-grey. Fracture fine grained foliated, sp. gr. 4.36. Occurs in quartz at Braunsdorf, and at Nagyag in Hungary.

Var. 3. Striated. *Strahliges graues spießglaserz*, Germ. *Antim. mineraliz. grif. radiatum*, Werner.

Its colour is light steel-grey, passing into a blackish grey, azure blue, golden yellow, and other splendid iridescent tints. It occurs disseminated, or in glandular mamillated and stalactitic masses or crystallized. The primitive form of its crystals has not yet been ascertained. Haüy has shewn that they are most easily and neatly divisible in one direction only, parallel to their axes; other natural joints are, however, discernible by the varying reflection of light from these surfaces when held before a candle. The only crystalline form that has hitherto been determined, is a compressed hexahedral prism, terminated by obtuse tetrahedral pyramids with trapezoidal surfaces (*antimoine sulfuré sexoedronal* of Haüy). See crystallographical plates, fig. 206. Incidence of n on s 134° ; of l on p $106^\circ 30'$; of l on s 146° . Born also mentions specimens from Hungary and Norway of truncated tetrahedral prisms. The surface of the crystals is generally marked longitudinally, with delicate striæ, and possesses much lustre. The internal lustre both of the amorphous and crystallized kinds is metallic and bright, or little shining. Its fracture is striated either broad or narrow, radiating, diverging, or implicated. When broken, it flies into irregular prismatic, or long granular fragments. Is soft and brittle. Specific gravity from 4.13. to 4.51. Its component parts, according to Bergman, are,

74 antimony,
26 sulphur,

100

The Hungarian antimony also contains a small variable proportion of gold.

This is the commonest of all the antimonial ores: it is procured at Kremnitz and Telsobanya in Hungary, at Draviza in the Banat, Braunsdorf in Saxony, the Black Forest in Swabia, Pereta in Tuscany, Lubillac in Auvergne, and Cornwall in England; also in Spain, Mexico, and Siberia. The splendid iridescent specimens come principally from Hungary.

Sulphurated antimony is sometimes confounded with oxyd of manganese; it may, however, be easily distinguished by the great ease with which it is fusible even in the flame of a common candle: it differs also from native antimony in exhaling, when heated, a sulphureous, and not an arsenical odour; in being of a darker colour, and leaving a dark grey trace when rubbed on paper.

It is found, for the most part, in primitive mountains, in micaceous schistus, and clay porphyry, mixed with pyrites and oxyds of iron: the gangue is sulphated barytes in Hungary, but elsewhere, for the most part, quartz; also, though rarely, chalcedony fluor and calcareous spar.

Sp. III. Plumose antimony. *Federerz, silber federerz*, Germ. *Mine d'argent grise antimoniale*, Delisle. *Antimoine sulphuré argentifère*, Haüy. *Antimonium plumosum mineralizatum argentiferum*, Born. *Antimonium mineralizat. griseum plumosum*, Werner.

The colour of plumose antimony is steel-grey, passing into greyish black, lead, or smoky grey: by exposure to the air, it tarnishes to an iridescent blue or yellow. It occurs in slender minute capillary crystals investing the surface of quartz and other minerals with a delicate brittle down or wool: the crystals are sometimes scarcely visible to the naked eye, and so implicated with each other, as to appear like an amorphous crust. According to Delisle, the form of the crystals is that of a compressed hexahedral prism, terminated by dihedral summits with pentagonal faces; the longitudinal striæ, however, are generally so strongly marked as to obscure the sides of the prism. Its lustre is semi-metallic, more or less glimmering. The fracture is confusedly fibrous, and the fragments are indeterminate. It is brittle: sp. grav. 3.57. Before the blowpipe it emits a smoke that deposits a white and yellow powder on the charcoal, and the residuum then melts into a black slag. No accurate analysis has yet been made of it; but, according to Bergman, it consists of antimony, iron, arsenic, sulphur, and sometimes silver.

This substance is ranked by many mineralogists among the silver ores; but improperly, as the proportion of silver is casual and variable, and never exceeds $\frac{3}{4}$ or 4 per cent.

It is met with in the Saxon mines, especially that of Himmelfurst near Freyberg; also at Stollberg in the Hartz, and Schemnitz in Hungary.

Sp. IV. Red antimony. *Roths spießglaserz*, Germ. *Soufre doré natif strié*, et *Kermes mineral natif*, Delisle. *Antimoine hydrosulfuré*, Haüy. *Antimonium auripigmento mineralizatum*, Cronstedt. *Antimonium mineralizatum rubrum*, Werner.

The colour of red antimony is a deep crimson approaching to blood red, sometimes, though seldom, clouded with iridescent blue. It occurs generally in minute short hair, or needle-form crystals, radiating or implicated: sometimes also it is found massive or disseminated. Its lustre is vitreous,

little shining. Its fracture is fine, and irregularly diverging fibrous. It is opaque, brittle but somewhat elastic: sp. grav. 4. to 4.7.

Before the blowpipe it melts easily and evaporates, exhaling a slight sulphureous odour.

The only mineral with which it is liable to be confounded is the red silky oxyd of copper: this last, however, is of a brighter colour, and dissolves with effervescence in nitrous acid, giving it a green tinge; the red antimony, on the contrary, is not dissolved, but becomes covered with a whitish crust. No accurate analysis has yet been made of this ore; from its colour it was formerly supposed to contain arsenic and sulphurated antimony: according to Sage, however, it is a native mineral kermes. Thus much is certain, that it is met with in the crevices, and investing the surface of the common sulphurated antimony, and appears to be this in an advanced state of natural decomposition: the amorphous or massive variety is frequently studded with small crystals of native sulphur, in the form of rhomboidal octahedrons.

It is met with at Braunsdorf in Saxony, Malazka and Cremnitz in Hungary, and Allemont in Dauphiné.

Sp. V. White antimony. *Muriated antimony*, Kirwan. *Weiss Spießglaserz, spießglanzspath*, Germ. *Muriate d'antimoine*, Born. *Antimoine oxydé*, Haüy. *Antimonium mineralizatum album*, Werner.

The colour of white antimony passes from snow-white through greyish and yellowish white into ash grey. It is seldom found massive, often radiating like zeolite, but generally crystallized in small and long quadrilateral prisms or rectangular tables, which are accumulated together in bundles or cells. The surface of the crystals is plain, or longitudinally striated, and bright shining or specular. Internally this mineral is much shining, or shining with a vitreous lustre passing into pearly. Fracture striat foliated. It flies when broken into irregular, not particularly sharp cornered fragments. Is translucent, soft, brittle, and heavy.

In whole crystals it decrepitates before the blowpipe; but when powdered, it melts quietly and without difficulty, giving out a white smoky, and by degrees totally evaporates. Between two coals it is reducible to the metallic state.

From the analysis of Klaproth, it seems to consist of antimony and muriatic acid; but the acicular variety from Dauphiné afforded Vauquelin,

86 oxyd of antimony,
3 oxyd of iron and oxyd of antimony,
8 silic,
3 loss.

100

This beautiful, but uncommonly rare fossil, was first discovered in 1782, by Mongez the younger, at Allemont in Dauphiné, mixed with native antimony; afterwards, in 1787, by Rössler at Przibram on the surface of galena: it occurs also at Malazka in Hungary, with the red and sulphurated antimony.

Sp. VI. Yellow antimony. *Supposed phosphorated antimony*, Kirwan. *Phosphate d'Antimoine*, Fr. *Gelb Spießglaserz*, Germ. *Antimonium mineralizatum flavum*, Werner.

The colour of this is orange or wax yellow, or yellowish white, passing into black when tarnished. It occurs in long striated needleform crystals, or quadrilateral tables. It is shining, and when black has a metallic lustre. Is soft, flexible, and heavy.

Before the blowpipe it neither flames nor smokes, but melts easily into a brittle slag, containing a small tin-white

bead of metal. It has not been analysed. This mineral was first discovered by Count Rasumawsky, in a vein of sulphurated antimony at Faucigny in Savoy, and has since been found at Malazka in Hungary.

Sp. VII. Antimonial ochre. *Spießglasocker*, Germ. *Antimonium ochraceum*, Werner.

Its colour is straw or lemon yellow, and yellowish grey. Occurs massive, disseminated or incrusting. Is dull; of a fine earthy fracture; soft, brittle, and heavy.

Before the blowpipe it becomes white, volatilizes, but does not melt. It effervesces strongly with borax, and is partially reduced. It has not yet been analysed, but is supposed by Karsten to be an oxyd of antimony.

It is found at Bräunörs near Freyberg, and in Hungary, mixed with sulphurated and red antimony.

Emmerling, vol. ii. Wiedenman, Handbuch, &c. Lenz, Versuch, &c. vol. ii. Haüy, Traité de Mineralogie, vol. iv. Delisle, Crystallographie, vol. iii. Kirwan's Mineralogy, vol. ii.

§ 2. Assay and Analysis of Antimonial Ores.

All the antimonial ores are easily reducible before the blowpipe on charcoal; and by a continuation of the heat, they exhale a dense smoke of a white or yellowish colour, with little or no arsenical odour, and deposit yellowish flowers, or white needleform crystals, on the surface of the charcoal: these appearances are, however, liable to considerable modification on account of the variable proportion of lead, arsenic, sulphur, &c. that are usually mixed with the antimony. A more certain, therefore, though not so expeditious a method of ascertaining the presence of this metal, is to reduce 200 grains of the ore to fine powder, and digest it in a moderately diluted nitro-muriatic acid, in which the nitrous is not more than one-third of the muriatic part. The clear liquor, after slow digestion for an hour, is to be decanted and reduced by evaporation to about half its bulk, and then poured into a large quantity of distilled water: a copious white precipitate immediately takes place of antimonial oxyd, which whenedulcorated and mixed with an equal weight of crude tartar, is to be put into a small lined crucible fitted with a cover, and by a moderate red heat the oxyd will be reduced into a metallic button.

The analysis of antimonial ores presents no particular difficulties, except such as are common to all minerals in which arsenic enters. The following are the substances which have been found mixed with antimony, viz. iron, silver, lead, copper, arsenic, and sulphur; to which must be added, silice and alumine, as composing the stony gangue, which cannot always be entirely separated previous to analysis.

(a) Let 500 grains of the ore be reduced in an agate mortar to an impalpable powder, and afterwards mixed in a flask with 1500 grs. of pure nitrous acid of sp. gr. 1.25, and 1000 grs. of distilled water; digest the mixture at a temperature considerably less than boiling, for an hour, then pour off the clear liquor, and add nitrous acid equal to half the quantity first used; digest this for a few minutes, and add by degrees, during the remainder of the digestion, half as much distilled water as acid; then pour off the clear liquor, and wash the residue with distilled water.

(b) Add together the two nitrous solutions and the washings, and drop in a saturated solution of muriated soda as long as any precipitate takes place, and allow it to stand for a few hours; pour off the liquor, and boil the precipitate in a little distilled water; filter andedulcorate. Add the washings to the liquor.

(c) The precipitate (b), consisting of muriated silver, and probably a little arsenic, being dried in a heat just inferior to its fusion, is to be weighed, and reduced in a small crucible by twice its weight of pearlsh: 75 parts of silver denote 100 of muriated silver, and if the produce of metal is less than that obtained by calculation, the deficiency may be set down as arsenic.

(d) The nitrous solution (b), containing a great excess of acid, is to be reduced to only a slight excess by the addition of potash or soda; and is then to be treated with nitrated barytes for sulphuric acid: the sulphat of barytes thus produced, contains the sulphur of the ore oxygenated by the nitrous acid. This being separated, add a saturated solution of sulphated soda, as long as any precipitation takes place. This is sulphated lead.

(e) The residue of solution (d), being evaporated to dryness, is to be mixed with soap, and heated in a subliming flask, the arsenic will thus be obtained in a metallic state.

(f) Upon the insoluble residue (a) digest two or three ounces of nitro muriatic acid, composed of nitrous acid 1, muriatic acid 5, water 3. By this the antimony, iron, and copper will be dissolved, together with a little alumine and silice. Separate this from the undissolved residue, and pour the liquor into three or four times its quantity of distilled water, and the oxyd of antimony will be precipitated. Separate this by filtration, wash, and add the washings to the other liquor: 130 parts of oxyd of antimony well dried denote 100 of metal.

(g) Evaporate the fluid (f) to a small bulk, and superaturate it with caustic ammoniac, the iron and earths will be precipitated, and the copper will be held in solution, giving it a blue colour. Separate the precipitate by a filter; and add sulphuric acid to the ammoniacal liquor till it becomes acidulous, then precipitate the copper by a bar of clean iron.

(h) The precipitate (g) being digested with a little caustic potash, the silice and alumine will dissolve, leaving the oxyd of iron behind.

(i) The undissolved residue of (f) being dried and weighed, is to be ignited to drive off the sulphur, the quantity of which is denoted by the loss of weight after ignition. What remains is earth and a few atoms of metallic oxyd, which being fused with black flux, will reduce the oxyd, and render the earths soluble in water.

(k) The sulphated lead (d) is to be reduced by fusion with tartar, and the oxyd of antimony also by the same method: being then weighed separately, as much pure lead is to be added as will make the lead twice the weight of the antimony. The metals being melted together are to be divided into two equal parts, and subjected to cupellation; if any silver remains, its amount is to be added to that of (c), Bergman's Ess. Klaproth's Analytical Essays. Kirwan's Mineralogy, vol. ii.

§ 3. Reduction of Antimonial Ores.

The grey or sulphurated antimony is the only one of this metal that is found in sufficient abundance for the purposes of manufacture, and the treatment that it undergoes is extremely simple. The larger pieces of the earthy or stony matter of the gangue being first picked out, the remainder is coarsely bruised, and subjected to a low red heat in close vessels: the sulphurated metal then melts on account of its very easy fusibility, leaving the impurities behind. This process is usually performed in a crucible, whose bottom, perforated with a number of small holes, is inserted into an-

other crucible. (See Chemistry, Plate iv.) A. B. *fig. 15*, or connected with the lower crucible by means of a pipe, *fig. 16*. In each apparatus the ore is put into the upper crucible, which serves the purpose of a filter, by detaining the stony impurities, while the melted metal flows into the lower receptacle. *Fig. 17, 18, 18, 19, 20, 21, 22*, are plans and sections of the furnaces generally made use of. This method, however, of extracting the ore is far from being the most economical possible, on account of the length of time necessary to charge a multitude of crucibles, the expence of replacing those that are broken, and the extra quantity of fuel required when the ore is not in immediate contact with the flame. On this account some of the founderies in Hungary and France have altogether discarded the crucibles, and melt the antimony in mafs by a reverberatory furnace, taking care to keep the surface of the metal covered with charcoal to prevent oxydation. *Fig. 23 and 24* are a plan and section of such a furnace. The rough ore being placed in the bed A, and covered with charcoal, is gradually brought to a state of fusion; and the plug at B being then withdrawn, the melted metal flows into the receptacle C. *Fig. 25, 26*, represent another kind of furnace for the same purpose made use of at Ramée in La Vendée. The sulphurated antimony thus obtained is remelted, and cast into loaves or cakes, forming the common or crude antimony of the shops.

§ 4. *Regulus of Antimony.*

The sulphurated ore of the preceding section having been long known by the name antimony, the term regulus of antimony was employed to designate the pure metal: in the reformed nomenclature, on the other hand, the former of these substances is called sulphuret of antimony, and the latter simply antimony. This ambiguity it is of consequence to be aware of, and we shall endeavour to avoid it as much as possible by using the term *regulus* of antimony wherever by so doing the sense may be made clearer.

The substance from which the regulus is prepared, whether in the large way for the purposes of commerce, or in the laboratory, is universally the native sulphuret. This consists of antimony and sulphur in the proportion, according to Bergman, of 74 of the former to 26 of the latter. Numerous methods have been proposed by different chemists for the separation of the metal, all of which may be conveniently arranged under the three following general heads. I. Reduction by roasting. II. Reduction by scorification. III. Reduction by dry parting or precipitation.

I. Reduction by roasting.

The native sulphuret of antimony being previously separated by fusion from all earthy impurities, as described in § 3, is to be pulverized and spread thinly on the floor of a reverberatory furnace or muffle, to be freed from its sulphur by roasting. At the commencement of the process the fire must be managed with particular care, and the temperature ought scarcely to be greater than what is necessary for the fusion of tin, otherwise the antimony will clog, and even melt, so as to require being removed from the fire, and again pulverized: as soon as the fumes of sulphur become visible to the eye, in the form of a light lambent blue flame, it is a proof that the heat is sufficient; and the ore should now be continually stirred with a tobacco-pipe, or any other earthen rod. In a short time the antimony will begin to oxydate, and assume a greyish earthy appearance; the fire may then be raised a little, to hasten the evaporation of the sulphur; and thus the operator may go on gradually increasing the heat as the ore will bear it; and continually

stirring it, so as to expose fresh surfaces to the air. When the ore is moderately red-hot, and ceases to give out a sulphureous vapour (which will not be till after some hours), the roasting is finished. By this means an ash-grey oxyd is obtained; still, however, not entirely free from sulphur, weighing from 30 to 36 per cent. less than the original sulphuret.

In order to obtain the regulus from this grey oxyd, the common way is to mix it with half its weight of crude tartar, and expose it in a covered crucible to a full red-heat: the tartar will thus be decomposed, its carbonaceous part serving to deoxygenate the antimonial oxyd; and its alkaline base combining with the sulphur still contained in the ore, forms sulphuret of potash, by which a portion of antimony is held in solution, while the rest of the regulus, by its superior specific gravity, unites into a mass at the bottom of the crucible. The quantity of regulus obtained by this means in the large way, is from 66 to 70 per cent. on the oxyd; but the produce depends essentially on the accuracy with which the roasting has been performed: if much sulphur still remains in the oxyd, a large proportion of the metal will be dissolved in the sulphurated alkaline scoria. Kunkel's method appears to be more economical, and better in every respect: he mixes the roasted oxyd with oil or fat and a little powdered charcoal, puts the mixture into a crucible to melt, and as soon as the regulus begins to shew itself, injects by degrees some powdered nitre, in the proportion of an ounce to a pound of antimony: the matter in thin fusion being poured out, a pure regulus is obtained in much greater quantity than by the common way. Most of the sulphurated ores, as those of lead and copper, are reduced to the metallic state after roasting by a simple carbonaceous addition, by which means the product of metal is greater than if an alkaline flux was made use of, and the whole expence of the flux is saved. Induced, therefore, by these motives and analogies, a series of experiments was undertaken by Hassenfratz, Vauquelin, and Buillon la Grange, to obtain the regulus of antimony by cheaper means than the use of tartar or nitre. For this purpose different parcels of the roasted grey oxyd were mixed with charcoal powder, with tallow and with pitch, and exposed in covered crucibles to a reducing heat; being then withdrawn, and the contents of each examined, nothing was found in the crucibles but a little carbonaceous matter, and a few minute globules of antimony, the rest being evaporated. Some grey oxyd was then mixed with, 1. equal parts of lime, alumine, and silice; 2. equal parts of sulphat of barytes, chalk and clay; 3. with common salt; 4. with sulphat or soda; and the materials being strongly heated, they were all found converted into yellow glasses, but not a particle of regulus could be perceived. The above four mixtures, with some charcoal rubbed up into them, were next treated as before: vitreous scoriae were obtained, but no greater quantity of regulus than when charcoal alone was made use of. Lastly, some of the same grey oxyd being fluxed with half its weight of tartar, yielded a perfect button of pure antimony. Hence it appears, that potash, and probably alkalies in general, exert some specific action on antimonial oxyd, which induces it to become much more fixed while converting into regulus, than when mere carbonaceous matter is employed.

II. Reduction by scorification.

This, although the most expensive and inaccurate method of procuring the regulus of antimony, is generally preferred in the laboratory to every other on account of its expedition. For this purpose the antimonial sulphuret is reduced to a fine

powder, and mixed with nitre and tartar; a crucible being then made red hot, successive spoonfuls of the mixture are gradually projected into it till the vessel is nearly filled; being then covered, and a full red heat applied for half an hour, the contents are either poured out into a greased iron cone, or suffered to cool in the crucible; a pure regulus is thus obtained, covered with a mass of saline scoriz. In this process the acid of the nitre is decomposed, and is employed in acidifying the sulphur and partly oxydating the antimony, while the carbonaceous matter of the tartar serves to de-oxydate the metal, and in some degree also to decompose the sulphuric acid; hence the scoriz consist of the potash of the nitre and tartar, partly united with sulphuric acid, forming sulphat of potash, and partly with sulphur, forming sulphuret of potash, which last also holds in solution a considerable proportion of the antimony.

If the quantities of nitre and tartar are large compared with that of the crude antimony, nearly the whole of the metal will be taken up by the scoriz. According to Lemery, sixteen ounces of sulphurated antimony, mixed with the same weight of nitre and also of tartar, yielded no more than five ounces and a half of regulus. Whereas fifteen ounces of crude antimony, twelve ounces of tartar, and six ounces of nitre, afforded six ounces and one dram of regulus. The usual proportions are four parts of crude antimony, with three parts of tartar, and one and a half of nitre. Some advise to detonate the nitre and tartar together, before the antimony is added, but this is decidedly a bad way, as the use of the nitre is not to alkalize the tartar, but to oxygenate the sulphur. A greater proportion of regulus than usual would probably be obtained by mixing the antimony and nitre alone, and not adding the tartar till after the detonation had taken place.

III. Reduction by precipitation.

This is effected by fusing the antimonial sulphuret with any other metal whose affinity for sulphur is greater than that of antimony, in which case the sulphur combines with the added metal, while the regulus of antimony collects in a button at the bottom of the crucible. The metals capable of thus decomposing the sulphurated antimony are iron, copper, lead, silver, and tin, whence originated five varieties of antimonial regulus, known among the alchemists by the names of martial, venereal, saturnine, lunar, and jovial. As equal parts of these metals require different quantities of sulphur for their saturation, a greater or less proportion of them is necessary for a given weight of crude antimony: thus two parts of this last substance are decomposed by one part of iron, by two parts of copper, or by four parts of lead.

In order to prepare the martial regulus (for all the others are now become obsolete), a number of formulæ are given by Lemery, Beaumé, and other practical writers, the relative merits of which can only be duly appreciated by a comparison of the quantity and purity of the regulus with the expence of time, of fuel, and of nitre, required in its preparation. The following are those which seem best worth notice:

1. Take eight ounces of horseshoe nails, and heat them nearly to whiteness in a crucible, then add, by degrees, sixteen ounces of coarsely pulverized antimonial sulphuret; cover the crucible and keep up the fire; in a few minutes the mixture will be in perfect fusion, at which time, add little by little, three ounces of nitre, a slight detonation will take place, and the whole will be brought to a state of perfect fusion; then pour it into an iron cone, heated and greased, and strike the sides of it gently as the mass becomes solid to favour the precipitation of the regulus. When cold it

will be found to consist of a button of antimony, weighing about ten ounces, covered with an alkaline ferruginous scoriz, from which it is readily separated by a blow with a hammer. This regulus, however, is far from pure, containing both iron and a little sulphur; it is therefore to be remelted, and mixed while in fusion with two ounces of crude antimony and three ounces of nitre; after all detonation has ceased, pour it into an iron cone as before; and separate the regulus from the scoriz. Remelt the regulus and project upon it by degrees three ounces of nitre. Separate this regulus from the scoriz, and melt it again once more with three ounces of nitre; heat it strongly and rapidly, and pour the whole into a cone; there will be obtained about eight ounces of a beautiful stellated regulus, covered with yellowish white scoriz. In this process the whole of the materials employed are eighteen ounces of crude antimony, eight ounces of nails, and twelve ounces of nitre; four separate fusions are required, and the product is eight ounces of regulus.

2. Pulverize and mix together 16 ounces of crude antimony, 12 ounces of tartar, 10 ounces of nitre, and eight ounces of iron filings; project it by degrees into a red hot crucible, a strong detonation will take place, and the mass will enter into fusion; keep it at a full heat for a few minutes, and then pour the whole into an iron cone; when cold, there will be found beneath the scoriz a pure stellated martial regulus, weighing about six ounces.

3. Heat in a crucible till they are white hot, five ounces of horseshoe nails, and then add 16 ounces of crude antimony, coarsely pounded; the two will presently melt down together, and as soon as the mass is in very liquid fusion, project at several times one ounce of pulverized nitre; during each projection there will be a detonation, and when the last has ceased, increase the heat for a few minutes, and then take out the crucible and allow it to cool gradually; there will be found at the bottom of the vessel a perfectly pure martial regulus.

In the reduction of antimonial sulphuret by iron, the success of the experiment depends much upon the temperature; a high heat briskly applied, and of short continuance, so as to bring the whole into very liquid fusion, is far preferable to an inferior heat of longer continuance: since the regulus separates more completely from the scoriz, and the proportion of metal, lost by evaporation, is not nearly so considerable.

The antimony obtained by roasting or scorification, by proper care, may be rendered absolutely pure; but the martial regulus, though purified so as to exhibit the stellated appearance on its surface, which is usually reckoned characteristic of purity, is, in fact, an alloy of antimony and iron; hence it is harder and more difficultly amalgamable than the former; and when reduced to fine powder, is, according to Lemery, attracted by the magnet.

§ 5. External Characters and Physical Properties of Reguline Antimony.

This metal, when perfectly pure, is of a dusky white colour, between that of tin and iron; it appears to be absolutely destitute of ductility, and may easily be reduced in a mortar to a fine powder; it is moderately hard, and may be cut without much difficulty by a common knife. Its fusibility is not quite so great as that of zinc, since it requires to be made red hot before it flows. Its specific gravity, according to Bergman, is 6.86; but by the later experiments of Brillon, amounts to 6.7021. Its fracture is usually broad foliated, but sometimes the facets are so minute as to give it almost a granular appearance; in general the slower it is cooled, the broader will be the plates of which it

is composed, but this rule is not without its exceptions. Antimony is one of the most easily crystallizable of all metals, and this tendency is shewn in a striking manner by the appearance of a radiated star, or of pinnated leaves, like those of fern, with which the convex surface of a mass of antimony that has been allowed to cool slowly is generally covered. It was this circumstance that induced the alchemists to pay so much attention to antimony; by their heated imaginations every thing singular was considered as a type or mysterious hint, and thus confounding sacred with profane, they denominated this appearance, which in truth is only the result of a confused crystallization, the eastern star that was to conduct the sages (themselves) to the cradle of their king, i. e. to the method of making gold, the king of metals. These rays or branches are merely superficial as Lemery demonstrated, by making transverse sections of various masses of stellated regulus. If a crucible, furnished with a plug at the bottom, is filled with melted antimony, and the fluid part allowed to run out by withdrawing the plug as soon as a crust is formed on the surface of the metal, there will be found under the crust various crystalline groups, consisting of cubes, of lengthened rectangular parallelepipeds, or ramifications, made up of small octohedrons implanted in each other, and frequently aggregated into a trihedral pyramid, with furrowed sides. The primitive crystalline form of antimony has hitherto eluded the sagacity of Haüy: it is divisible at the same time parallel to the faces of a regular octohedron, and of a rhomboidal dodecahedron.

§ 6. *Oxyds of Antimony.*

The action of air and moisture at the usual temperature upon reguline antimony is scarcely perceptible, as it remains a long time without even tarnishing, and the oxydation is never more than merely superficial. By a low red heat, however, and the contact of air, this metal is gradually converted into a greyish white oxyd, volatile at a higher heat, and capable of being more completely oxygenated. When antimony is brought quickly to a bright red heat, and then exposed to the air, is rapidly converted into a white oxyd, which being volatile, exhales in the form of a dense smoke from the surface of the melted metal, and condenses in the upper and cooler part of the crucible into beautiful crystalline needles of a snowy or silvery white; which have obtained the name of argentine flowers of antimony, or snow of reguline antimony. As this crystallized oxyd is not easily obtained in a common crucible, we shall mention the method of preparing it as given by Beaumé. "Place a wide cylindrical earthenware tube closed at one end in a wind furnace, so that it shall remain in a slanting direction, with the open end protruding a little way through a hole or door in the side of the furnace; and to prevent the inside of the tube from being too much cooled, an earthenware stopper must be prepared to fit loosely into the open mouth of the tube.—The apparatus being properly put together, light the fire, and when the bottom of the tube is red hot, introduce the antimony in small pieces, and close the mouth of the tube with the stopper. The metal being melted, will begin in a short time to smoke, and the crystalline oxyd will be deposited in the upper part of the tube, from which it may be scraped from time to time with a clean iron spoon. The first portions are generally yellowish on account of a small quantity of sulphur contained in the metal; this, however, is soon burnt off, and the succeeding flowers are of a pure brilliant argentine white colour." Although antimony is not combustible at so low a temperature as zinc, yet, at a white heat, with access of air, it burns with a white flame, throwing out copious vapours of white oxyd. Another

pretty experiment on the inflammation of antimony, was discovered accidentally by Cit. Gillet. Place a small piece of antimony on a bit of charcoal, and fuse it by the blowpipe; when it is boiling hot, shake it gently out so that it may fall three or four feet through the air; it presently divides into a few globules, which immediately take fire, and explode when they reach the ground like fireworks.

The crystalline oxyd, like the other white oxyds that we shall have occasion to notice in the next section but one, appears to be a saturated combination of antimony and oxygen, in the proportion, according to Thenard, of 80 of the former to 20 of the latter; in many of its properties it resembles the metallic acids; it is soluble, though but sparingly, in water, has a decided taste, forms a crystallizable salt with potash, from which it may be separated by the action of any of the stronger mineral acids. When heated by itself in a porcelain tube, it may be reduced nearly to the metallic state; the first impression of the fire converts it into a yellow oxyd, very easily fusible into glass, and containing 0.19 of oxygen; afterwards, as the heat increases, it assumes a reddish brown tint, and holds only 0.16 of oxygen; at length it arrives at the state of black oxyd, wanting only to be deprived of 0.02 of oxygen, to return to the metallic form. Oxyd of antimony, by hasty fusion in a crucible, is converted into a vitreous mass, which, when transparent, is of a yellowish orange colour, and is called *glass of antimony*; and when opaque, is of a brown colour, and has hence obtained the name of *liver of antimony*. These preparations, however, must not be confounded with the glass and liver of antimony, as procured from the sulphuret of this metal.

§ 7. *Action of Acids on Antimony.*

1. The *sulphuric acid*, when cold, appears to exert no action on antimony; but when boiling hot, it is decomposed by this metal, a copious extrication of sulphureous acid gas takes place, accompanied by violent effervescence; and if the mixture is distilled to dryness in a retort, a small quantity of sulphur sublimes, and a mass of white antimonial oxyd is at the bottom of the vessel. When the process is stopped short of desiccation, there remains in the retort a white, bulky, soft, and moist mass, and this, when washed with a little water, occasions a copious deposit of white oxyd, while the clear liquor becomes diluted sulphuric acid, holding in solution a small portion of antimony; a larger quantity of water added to this liquor, precipitates what remains of antimonial oxyd. The action of heat also has the same effect, for while evaporating it becomes turbid without forming crystals; the same takes place on the mixture of any alkaline solution. If the unwashed sulphated oxyd of antimony is mixed with common salt and distilled, the result is oxymuriat, or butter of antimony.

2. *Sulphureous acid*, whether hot or cold, has no effect whatever on reguline antimony; it will, however, decompose most of the acid salts of this metal, especially that formed by muriatic acid. If sulphureous acid is added to a solution of muriated antimony, a white powder is thrown down of an acrid and harsh taste, which appears to be a true insoluble sulphite of antimony, decomposable with extrication of the sulphureous acid by the sulphuric, or by mere heat in close vessels; the residue of this last operation is a reddish brown matter, soluble in fixed alkali, and again precipitable by the muriatic acid in form of kermes, or hydrosulphurated oxyd of antimony.

3. *Nitric acid*, especially the yellow, is speedily decomposed on antimony, even in the cold. During the mutual action of these two bodies, a large disengagement of nitrous gas takes place, and the metal is converted into a white oxyd so rapidly, as sometimes to cause actual inflam-

tion. In its eager absorption of oxygen, a great analogy subsists between antimony and tin; for not only the nitric acid, but even the water that is mixed with it, are decomposed by the antimony; the azot of the former, and the hydrogen of the latter of these fluids, combine together during their nascent state, and produce ammonia, which with the undecomposed acid, forms nitrated ammonia, the crystals of which salt, thus unexpectedly occurring, have sometimes been mistaken for nitrat of antimony. If the white oxyd, resulting from this chemical action, is mingled, before it has been washed, with lime or caustic alkali, ammoniacal gas will be disengaged. The greatest part of the antimonial oxyd remains uncombined at the bottom of the vessel; a very small quantity, however, is taken up by the supernatant acid; but even this little is precipitated by water, by evaporation, and by mere standing for a few days. The white nitrous oxyd is fully saturated with oxygen, of which it contains, according to Thénard, about 30 per cent. It is considered as one of the most refractory and irreducible of the metallic oxyds, which it certainly is when treated with the common fluxes; but when rubbed with a little regulus of antimony, and heated in a close vessel, it becomes in succession yellow, orange, brown, and then black; containing only about two per cent. of oxygen, as is related of the argentine flowers in the former section.

4. *Muriatic acid*, when assisted by heat, is capable of dissolving a small proportion of antimony; part of this, however, is again deposited in the form of a white oxyd as the liquor cools: by evaporation it may be brought to crystallize in small acicular deliquescent needles. The oxyd of antimony is more easily soluble in muriatic acid than the metal itself, and also in greater proportion: it crystallizes, according to Monnet, in brilliant plates, like the boracic acid, and is decomposable by water.

5. The *oxygenated muriatic acid*, when in the form of gas, exerts a very striking action on reguline antimony: if this metal, previously reduced to a fine powder, is thrown by small quantities at a time into a vial filled with the acid gas, each parcel will be found to take fire, and burn with a white flame, throwing out, at the same time, a number of bright sparks, and thus forming a most beautiful shower of fire. The antimony is converted into a white muriated oxyd. The liquid oxymuriatic acid changes the metal into a powdery oxyd, but holds a very small quantity of it in solution; no doubt on account of the great proportion of water, which even the most concentrated liquid oxymuriatic acid necessarily contains. If a solution of either the muriat or oxymuriat of antimony be gently evaporated nearly to dryness, and afterwards exposed in a retort to a low sand heat, a thick oleaginous liquid will come over, that by cooling concretes into a soft mass, called, from its consistence, by the ancient chemists, *butter of antimony*; the above, however, is not the actual method of preparing this salt in the laboratories; it is more expeditiously made by taking advantage of the superior affinity which antimony has over mercury: for this purpose some reguline antimony is well mixed in a mortar with twice or two and a half times its weight of oxymuriated mercury (corrosive sublimate); during trituration, much heat is extricated, the evidence of a chemical action between the two substances: the mixture being put into a wide necked retort, with a suitable receiver adapted, is exposed in a sand bath to a gentle heat. During the first half hour, a small quantity of a clear liquid passes into the receiver, which is afterwards followed by a thick liquor that concretes by cooling in the receiver, and often in the neck of the retort into a white mass; this is the *butter of antimony*. A moderate fire is

kept up till nothing more comes over, at which time the receiver is unluted, and emptied of its contents; there remains in the retort fluid mercury with some muriated oxyd of antimony. By continuing the distillation at a greater heat, the mercury is volatilized, and collected in a liquid state in the receiver. It is to be remarked, however, that there are two objections to this process; the one, that if the mercurial salt is in too great proportion, a little of it will rise with the butter of antimony, and be dissolved in it; the other objection is, that if too little oxymuriat is used, the produce will be much diminished, as a considerable proportion of the antimony will be merely in the state of muriated oxyd. The best way, therefore, of preparing this salt, is to mix the unwashed sulphat of antimony (1. § 7.) with common salt and black manganese, and distil the whole to dryness.

The London Pharmacopœia orders the sublimed muriat to be made thus. Mix together one part of crocus of antimony with two parts of decrepitated salt; put the mass into a glass retort, and add one part of sulphuric acid; then distil, and what comes over is butter of antimony.

Butter of antimony, though solid at the usual temperature of the atmosphere, liquefies at a very gentle heat, and by slow cooling crystallizes in large parallelepipedes. It is intensely caustic, destroying the organization both of animal and vegetable substances; by exposure to the air and light it becomes coloured, and deliquesces into a thick oleaginous fluid. When dropped into distilled water, it is for the most part decomposed, and a copious white precipitate is thrown down, which is little else than a perfect oxyd of antimony. This, after being washed and dried, forms the *powder of ALGAROTH*, or *mercurius vitæ*. The clear liquor separated from the precipitate still holds a little antimonial oxyd in solution, as is obvious from a further precipitation taking place on the addition of an alkali.

Scheele has given the following method of preparing powder of algaroth, in an essay of his on this very subject. To two parts of sulphurated antimony add three of nitre, and detonate the mixture in a hot crucible; pulverise the mass, and stir in one part of this to three of water, with one of sulphuric acid, and one of common salt. Let the whole digest together for twelve hours in a sand bath, and strain it through a cloth; separate the clear liquor, and add to the residue more salt and diluted sulphuric acid, which digest and filter as before. Mix the two liquors together, and pour them into a large quantity of boiling water; a white precipitate immediately takes place, and this, when washed and dried, is the powder of algaroth.

If to any quantity of sublimed muriat of antimony an equal weight of nitric acid is added, the liquor becomes highly coloured, copious orange-coloured fumes are disengaged, and a considerable degree of heat is excited; after a while, a white magma of oxyd is deposited. If before the latter effect takes place, the liquor is evaporated to dryness, a pure white oxyd remains behind; and this being three times more abstracted with fresh nitric acid, and afterwards heated moderately red in a crucible, assumes the appearance of a pulverulent mass, white at the surface, and rose-coloured beneath; this being ground in a mortar, so that the white and coloured parts may be thoroughly mixed, is known in the shops and old pharmacopœias by the name of *bezoar mineral*; and, in fact, is nothing more than a perfect oxyd of antimony, holding, perhaps, a very small portion of the acid.

6. *Nitro-muriatic acid* is the best solvent of reguline antimony; if the acid is made moderately warm, and the metal put in by small pieces at a time, taking care not to

add a second till the first is completely dissolved, it may be thus charged with a considerable proportion of antimony, only a small part of which is deposited by cooling. This, however, like all the preceding antimonial solutions, is almost wholly decomposed by the addition of distilled water. A piece of iron or zinc also causes a precipitation of a black oxyd (§ 6.), almost in the metallic state, which, according to Theuars, when dried at a low temperature, acquires the properties of a pyrophorus, inflaming spontaneously by contact with the air.

7. The *fluoric, boracic, and carbonic acids*, have no action on reguline antimony; they are capable, however, of combining with its oxyds, forming salts, the particular properties of which have not been examined.

8. The action of all the *metallic acids* on antimony, except the arsenic acid, is wholly unknown: and for this see *ARSENIAL of Antimony*.

9. The *veget. ble acids* produce no other effect on metallic antimony, except blackening its surface; they dissolve, however, its oxyds without much difficulty, forming salts, a few only of which have been properly examined: these we shall proceed to particularise.

10. The *antimoniated tartar, or emetic tartar*, is the most important of the combinations of antimony with the vegetable acids. It was first prepared by Adrian Mynsicht, in 1631; and from that time to the present, has attracted the notice of chemists and physicians. Bugman, in his admirable essay on Emetic Tartar, was the first who gave any thing like a consistent account of the rationale, and the various chemical affinities concerned in its preparation; and the subject has of late been finally elucidated by the able and sagacious experiments of Theuars.

The tartareous acid, the acidulous tartrate of potash (or cream of tartar), and the tartrate of potash (soluble tartar, or tartarized tartar), are each capable of dissolving and combining with oxyd of antimony; an inquiry, therefore, into the chemical properties of emetic tartar, necessarily includes the consideration of the above different menistrua, and thus renders it a very complicated affair.

Pure tartareous acid and boiling water, digested on any of the oxyds of antimony, except that which is saturated with oxygen, as the diaphoretic antimony, may be made to take up one-third or one-fourth part of its own weight; and the solution, when concentrated by evaporation, and allowed to cool gradually, usually deposits a few crystalline grains, but is for the most part converted into a brownish gelatinous mass, which, at a red heat, is charred, and the antimony contained in it is partly extricated in the form of a white smoke, and partly reduced to metallic grains.

A solution of tartrate of potash, at a boiling temperature, takes up at least as much oxyd of antimony as tartareous acid is capable of dissolving; the liquor becomes slightly alkaline, and upon evaporation, yields a number of crystalline grains.

A solution of tartareous acidulum, or cream of tartar, being boiled with any of the simple oxyds, or sulphurated oxyds of antimony, dissolves a considerable quantity; and by evaporation and cooling, deposits elongated octahedral crystals of emetic tartar.

The taste of this triple salt is slightly harsh and metallic; it reddens vegetable blues; it effloresces in the air, loses its transparency, becomes of a dead white, and is then pulverulent: it requires for its solution about 40 times its weight of boiling water, and nearly twice as much at the common temperature. Sulphuric acid precipitates from it a sulphated oxyd of antimony, leaving the cream of tartar pure; the alkalies, both pure, and carbonated, decompose it in part only, a loose white oxyd being

precipitated by the first, and by the second, a carbonated oxyd, which, in a short time, crystallizes in the form of divergent rays. If either tartareous acid, or tartrate of potash, is added to the solution of emetic tartar previously to pouring in the alkali, there will be no precipitate; for the tartrate of potash produced by the alkaline addition, or already existing in the fluid, immediately dissolves the antimonial oxyd; and for the same reason, a simple solution of emetic tartar cannot be wholly decomposed by any quantity of alkali; and hence probably have arisen the great seeming differences in the proportion of its constituent parts, as the salt has been analysed by means of a pure alkali, a carbonated alkali, or other re-agents. According to Theuars, the crystals of emetic tartar, from whatever antimonial oxyd they are prepared, and whatever has been the proportion of ingredients employed, contain in a given weight precisely the same quantity of antimony, of tartareous acid, of potash, and water; and even the degree of oxydation of the metal is also invariable. His method of analysing this salt, is first to ascertain its water of crystallization, by drying in a heat just not sufficient to decompose it; secondly, to dissolve the emetic tartar, and precipitate the antimony by sulphurated hydrogen; thirdly, to ascertain the tartareous acid by dropping in acetite of lead; fourthly, to determine the quantity of potash by igniting the residue, and extracting the alkali by dilute nitrous acid. By a very careful analysis, conducted in the above manner, he found 100 parts of emetic tartar to contain 38 oxyd of antimony, 34 tartareous acid, 16 potash, and 8 water, besides 4 loss. But the tartareous acidulum, which supplies both the acid and alkali to the emetic tartar, contains 57 tartareous acid, 33 potash, and about 10 water and loss; or 70 tartrate of potash, and 20 tartareous acid in excess. Hence it follows, that there is a greater excess of tartrate of potash in cream of tartar over the acid, than exists in the emetic tartar; and this excess of tartrate of potash is found in the mother water, in which the crystals of the emetic are decomposed; when, therefore, the whole is evaporated to dryness, as is often the case in the preparation of emetic tartar, there is a portion of antimoniated tartrate of potash superadded, which, no doubt, modifies its effect, and produces variations, which are unjustly changed to the emetic tartar. Another objection to evaporating the whole mass to dryness without separating the crystals, is, that the tartrate of lime which exists in a variable proportion in all cream of tartar, according to Vauquelin, is also mingled with the antimonial salt, and weakens its operation. To make, therefore, emetic tartar uniformly of the same strength, select an antimonial oxyd somewhat below the maximum of oxydation, and digest it in a hot saturated solution of cream of tartar, taking care that the oxyd shall be rather more than enough to saturate the salt (if the grey oxyd from the sulphuret of antimony is made use of, or even the common glass of antimony, as these are not already sufficiently oxydated, there will be a decomposition of water, and a small quantity of kerms will be formed); when the liquor refuses to take up any more antimony, filter and evaporate till a pellicle begins to be formed; allow the solution to cool, and select all the octahedral and tetrahedral crystals that are deposited; wash them in cold water, and again dissolve in hot water, and crystallize. For the particular formulæ of the different pharmacopœias, see § 12.

11. The only remaining antimonial salts of any consequence, are the oxalat and acetite of antimony; and we are as yet acquainted with very few particulars even concerning these. The oxalat of antimony is easily formed, and concretes into small crystalline grains; these are soluble in wine, giving it an emetic quality; and this preparation has

been used by some medical men instead of the common antimonial wine. The acetite of antimony being known before the discovery of emetic tartar, was recommended for the same uses to which the former is now applied, by Angelo Sala. Neither the oxalat, nor the acetite, however, of this metal appear to be possessed of any superiority over the emetic tartar, and are now, we believe, wholly disused.

§ 8. Action of Neutral Salts on Antimony.

Muriat of soda is said to be in part, at least, decomposable by antimony at a red heat; but the experiments on this subject are contradictory, and require to be performed afresh with care and exactness.

Sulphat of potash (and probably all the alkaline sulphats), is decomposed without any difficulty. This was first shewn by Monnet; he fused together in a crucible two parts of sulphated potash, and one of antimony; the metal disappeared, and he obtained a yellow, semi-vitrified mass, intensely caustic, of antimoniated sulphuret of potash; which, when washed with warm water, deposited, by cooling, a hydrosulphurated oxyd of antimony. The metal, therefore, in this case, became oxydated at the expence of the sulphuric acid; and the sulphuret of potash resulting from this combined with the metallic oxyd, rendering it partly soluble in hot water.

Oxymuriat of potash has a very powerful action on antimony, as it has indeed upon all the easily combustible metals: if equal parts of this salt, and antimony previously reduced to a fine powder, are mixed together, and struck briskly on an anvil, or any suitable hard body, a remarkably loud and vehement detonation takes place: if the mixture, instead of being struck, is poured into sulphuric acid, or rather if the acid is poured upon the powder, a hissing noise is produced, red sparks are emitted, and the metal is converted into an oxyd.

Nitre and antimony, in equal parts, or two parts of the former to one of the latter, being thrown into a red-hot crucible, detonate with a vivid flame, the acid of the nitre is decomposed, and the metal is completely oxygenated. The white mass remaining in the crucible being pulverised and digested in hot water, is separated into two parts, one soluble, and the other insoluble: the latter of these was formerly considered as a pure oxyd of antimony, but Theuvs has shewn, that it contains about one-fifth of potash, intimately united with the oxyd, which appears to act the part of an acid: it was formerly known by the name of *reguline diaphoretic antimony*, but appears, in fact, to be a kind of *antimonite of potash*, rendered insoluble by an excess of oxyd; the soluble part differs from the other merely in the proportion of its ingredients, being an *antimoniated potash*, crystallizable and decomposable, with precipitation of its oxyd, by any of the mineral acids. As, however, this is generally prepared from the sulphuret of antimony, we shall refer the reader for further particulars to the next section.

§ 9. Sulphuret of Antimony—Glas of Antimony—Kermes, &c.

1. Sulphuret of antimony may be prepared artificially, by pulverizing a pound of reguline antimony, and mixing with it eighteen ounces of flowers of sulphur; this being put into a crucible, and brought to a low red heat, melts into a uniform mass, of the weight of about two pounds, which, when cold, exhibits a striated appearance, exactly similar to the native grey sulphuret (§ 3.), and is possessed of all the same physical and chemical properties; hence, for cheapness sake, all the preparations from the antimonial sulphuret are made with the native ore, just separated by fusion from the stony and earthy matters that it is mixed with, which is

known in commerce by the name of *crude antimony*, or antimony of the shops.

2. If the sulphuret of antimony is exposed to a red heat, with access of air, most of the sulphur is volatilized, and a small but variable proportion of the metal is carried up at the same time: this operation being performed in a melting-pot, surmounted by a series of aludels, the vapour as it rises, is condensed in the form of a light pulverulent substance, called *flowers of antimony*. The flowers, at the beginning of the process, are of a greyish yellow colour, and consist of sulphur, with antimony, either in the metallic state, or at least very little oxydated; the next portions are orange-coloured, and those which rise towards the end of the operation, are almost yellow, and consist of little else than pure sulphur. What remains behind at the bottom of the melting-pot is a greyish ash-coloured oxyd, still holding a little sulphur: among the old chemists it was known by the name of *grey calx of antimony*; by the moderns it is called the *grey sulphurated oxyd* of antimony. It is most commonly prepared by slow roasting of the crude antimony in a flat dish or reverberatory furnace, and the sulphur and metal that are volatilized with it are allowed to escape. See § 4.

3. The grey sulphurated oxyd, when urged by a sufficient degree of heat, forms a transparent glass, possessing, according to circumstances, every shade of colour from light yellow to the deepest hyacinthine red; this is the *glas of antimony*, or, according to the modern nomenclature, the *vitreous sulphurated oxyd* of antimony. In order to prepare this, any quantity of the grey oxyd is put into a crucible, and kept at a full red or low white heat till it enters into perfect fusion; soon after this has taken place, the end of a clean tobacco pipe should be dipped in it; and if the matter that adheres to the pipe is transparent, and may be drawn into a thread like common glass, it has been heated sufficiently: the crucible is then to be removed from the fire, and its contents are to be poured on a compact flat stone or plate of copper. When the glass has become solid, it should be removed into a covered vessel, as it cracks and flies while cooling.

It sometimes happens in making the glass of antimony, that the grey oxyd begins to melt as soon as it is red hot, and continues limpid like water, without acquiring the property of drawing into threads like glass: at other times, on the contrary, even the long continuance of a white heat will do no more than bring it to a pasty consistence. In the former case, the glass is of an unusually deep colour; in the latter of a very light colour. This inequality arises from a difference in the grey oxyd; if it has been too little roasted, it flows with the first impression of the heat, but when more completely oxydated and desulphurated, it proves very refractory: this last, however, may be remedied by throwing in a little crude antimony in powder, which will immediately determine its fusion and vitrification; and in this case there are always found at the bottom of the crucible a few grains of very pure regulus of antimony.

If the previous desulphuration has been very slight, the oxydation also will have proceeded but a little way; and the glass produced, though possessed of a vitreous fracture, is perfectly opaque, and of a dark liver colour, hence it has obtained the name of *liver of antimony*: the same name, however, has been given to a preparation of crude antimony and nitre, which will be mentioned presently.

4. The action of acids upon the sulphuret of antimony is upon the whole so similar to their action on the regulus, as described, § 7, that it will only be necessary to point out the circumstances in which they differ. In general, the metallic part of the sulphuret is more easily dissolved and re-

tained by acids than the mere regulus is, and the sulphur of the compound is not at all or very little acted upon. The sulphuric and nitric acids are decomposed with considerable energy, on pulverized sulphuret of antimony; sulphureous acid in one case, and nitrous gas in the other, being copiously disengaged, the metal is oxydated, and remains intimately mixed, though no longer combined with the sulphur, very little of it being actually dissolved by these acids. The muriatic acid, even when cold, will decompose a large quantity of sulphuret, during which process, there is a considerable extrication of sulphurated hydrogen; if the mixture is heated, the whole of the metal enters into solution, leaving the sulphur at the bottom unaltered; a small portion, however, both of the sulphur and metallic oxyd is dissolved in the hydrogen, and escapes in a gaseous form; for Bergman observed, by performing this experiment in a vessel with a long narrow neck, that the sulphurated hydrogen, in its passage through, deposited a little kermes, or hydrosulphurated oxyd of antimony. The best menstruum, however, for crude antimony, is a nitro-muriatic acid, composed of one part nitric, and three parts muriatic acid; the metallic oxyd is entirely taken up, part of the sulphur is carried off by the hydrogen gas, another part is acidified and mixes with the other acids, and the remainder, about 26 per cent. is left at the bottom of the vessel in form of a white powder. In § 7, we have given an account of the original method of preparing the butter of antimony by sublimation of the regulus with corrosive mercurial muriat: the same antimonial salt may be obtained by using sulphuret of antimony, but instead of obtaining the mercury in a metallic state, it is combined with the sulphur of the antimony into a violet-coloured mass, which, at a full red heat sublimes, and is deposited in the upper and cooler part of the vessel, in needle-form crystals of cinnabar, hence called *cinnabar of antimony*.

5. The fixed alkalis are capable by the dry way of combining with sulphurated antimony, forming several important preparations. If 15 ounces of pulverized crude antimony, 12 ounces of decrepitated sea salt, and 3 ounces of tartar, are mixed together, and fused in an earthen crucible, there will be found, on breaking the vessel when cool, that it contains two substances; the upper is of a lighter colour than the other, and consists of the salt with a little sulphur; the inferior substance is very heavy, opaque, of a black colour, and on being broken, exhibits a shining vitreous fracture: it has obtained the name of *medicinal regulus*, though improperly, being a simple alkaliized sulphuret of antimony, in which the metal is probably uncombined with oxygen, and nearly saturated with sulphur. A similar preparation to this is the *ruby of antimony*, or *magnesia opalina*, differing, however, in containing less sulphur, and in the metal being perhaps more oxydated. It is prepared by mixing equal parts of muriated soda (sea salt), nitre, and crude antimony, and fusing the whole in a crucible; there is a large quantity of scoria in this as in the former process, and underneath them is a compact vitreous mass, transparent in thin shivers, and, if well made, of a deep, somewhat smoky-red colour, and brilliant semi-metallic lustre. Neither of these preparations is deliquescent or soluble in water, on account of the small proportion of alkaline salt that they contain. By increasing, however, the dose of alkali, the mass becomes soluble; thus, if to one part of sulphurated antimony we add two parts of pure dry pearl ash, we obtain by fusion a compact reddish-brown mass of alkaline sulphuret of antimony, and a little of the metal in its pure reguline state is found at the bottom of the crucible. If the whole of the antimony is required to be dissolved in the sulphurated alkali, as is the case in the preparation of kermes, it is requisite to add to the above ingredients about

one-twentieth of their weight of sulphur. Hence it appears, that the sulphur of the crude antimony is divided between the metal and the antimony, in the compound ratio of their weights and their respective affinities for sulphur, in consequence of which some of the antimony is entirely desulphurated, and remains in an uncombined state, while the remainder being only partially desulphurated, unites into one mass with the sulphurated alkali. If this alkaline sulphuret of antimony, coarsely powdered, is boiled in pure water, nearly the whole is held in solution as long as the liquor continues hot, so that it may be passed hastily through a filter; but in proportion as the liquor cools, a copious precipitation takes place, of a bulky, flocculent substance, whose colour is a deep brick-red, approaching to that of the kermes insect, whence it has been called *kermes mineral*: after the deposition of kermes has ceased, the liquor being separated from it by a filter, is of a wine-yellow colour; and upon the addition of any acid, a still further precipitation is brought about, of an orange-yellow powder, which is called the *golden sulphur of antimony*. Kermes may also be prepared in the humid way, as was first shewn by Lemery in the year 1707. Since that period a multitude of processes have been published by the French chemists for the preparation of this substance; none of them, however, appear to be essential improvements of Lemery's original method; and as this has received the high sanction of the observant and accurate Beaumé, we shall select it for the use of our readers. Put into a clean iron pan five or six parts of pure liquid fixed alkali, with fifteen or twenty parts of water; set it over the fire to heat, and as soon as it has begun to boil, stir in some well levigated sulphuret of antimony, equal in weight to one-sixteenth of the alkali; stir the mixture well, and when it has boiled for a minute or two, throw the whole on a filter, so that the clear liquor may pass through while hot; a large quantity of kermes will be deposited while it cools, which, after being separated from the alkaline solution, is to be washed first in cold, and then in hot water, till the water comes off quite insipid; the powder being then dried in the shade by a gentle heat, and levigated and passed through a fine sieve, is to be kept in a well-closed phial for use. The alkaline liquor, when it has ceased to deposit kermes, may be made to yield the golden sulphur, by saturating it with dilute sulphuric acid. In this process by the humid way, as in the other by the dry way, a partition of the sulphur takes place between the alkali and the metal, by which a portion of this last is left undissolved in the form of a grey powder; and this, by simple fusion in a crucible, is reduced to a mass of regulus. According to the French chemists, both the kermes and golden sulphur are *hydrosulphurated oxyds of sulphuret of antimony*: and Theuars, in his experiments on the antimonial oxyds, has given the following as the result of his analyses of these two substances, viz. Kermes mineral contains,

72.760 brown oxyd of antimony,
20.298 sulphurated hydrogen,
4.156 sulphur,

97.214
2.786 loss.

100.000

Golden sulphur contains,

68.3 orange oxyd of antimony,
17.877 sulphurated hydrogen,
11 to 12 sulphur.

98.177

The theory concerning their formation is, that the alkaline antimonial sulphuret coming into contact with water, decomposes it; that the oxygen of the water combines with the sulphurated metal, while its hydrogen dissolves some of the sulphur with which it is in contact, and unites to the sulphurated metallic oxyd in different proportions, according to the different degrees of oxydation of these oxyds: that when the antimony is the least oxydated, it unites with the greatest quantity of sulphurated hydrogen, and becomes insoluble in alkali, forming the kermes; and, on the other hand, when more oxydated, it unites with less sulphurated hydrogen, and remains dissolved in the alkali till precipitated thence by an acid, forming the golden sulphur. Kermes may also be made by passing sulphurated hydrogen through a solution of muriat of antimony; and this among others is adduced as a proof of the kermes containing the metal in an oxydated state. Notwithstanding, however, the excellent experiments of Berthollet and Theuars on this subject, many very strong objections may, in our opinion, be urged against their theory: to enter into them at full length would be inconsistent with the plan of this work, but we shall resume the subject when treating of the *Metallic Hydrosulphurets*.

6. The nature of the preparations resulting from the mutual action of nitre and sulphurated antimony, depends very much on the proportion which the nitre bears to the other ingredient. The nitrous acid is consumed in acidifying the sulphur and oxydating the antimony; and the alkaline base of the nitre unites with the sulphur, if any remains, with the sulphuric acid forming sulphat of potash, and with the metallic oxyd. When the nitre considerably exceeds the antimonial sulphuret, as in the preparation of diaphoretic antimony, the sulphur is entirely oxygenated, and partly escapes in the form of sulphurous acid gas, while the remainder, with part of the alkali, forms sulphat and sulphite of potash; the metal also is completely oxygenated at the expence of the nitre; and the oxyd hence resulting, combines with the potash in two proportions; that portion which is united to a large quantity of alkali is rendered soluble, and the other remains insoluble. Hence when the result of the above process is lixiviated with hot water, we find dissolved in the liquor, and may obtain, in a crystalline form, sulphat and sulphite of potash, some undecomposed nitre, and antimonite of potash; the undissolved residue, or diaphoretic antimony, consists of the perfect oxyd of antimony combined with about a fifth of potash.

When the nitre and crude antimony are in equal proportions, only part of the sulphur is acidified, and the metal is at a low state of oxydation; by the action of warm water the mass is divided into an insoluble and soluble portion; the first, called *crocus metallorum*, seems, like the glass of antimony, to be merely a sulphurated oxyd; the latter consists of kermes, of golden sulphur, and sulphat of potash. For further particulars see § 12.

§ 10. *Phosphuret of Antimony.*

Pelletier, in his *Essays on Phosphorus*, has given the three following processes for combining antimony with that highly inflammable substance. 1. To one ounce of regulus of antimony add an equal weight of glass of phosphorus, and one dram of charcoal; pulverize the whole well together, and fuse the mixture in a covered crucible; the result is a white metallic mass of phosphorated antimony, very brittle, with a lamellar fracture, and nearly cubical fragments. When a little piece of it is put upon lighted charcoal, and exposed to the action of the blowpipe, it emits, at the moment of fusion, a faint green flame, and then volatilizes like pure antimony, in the form of white flowers.

2. Equal parts of regulus and glass of phosphorus furnish by fusion a metallic mass, whose fracture displays minute facets, and in every other respect is similar to No. 1. 3. A phosphuret of antimony, with the same properties as the former, may also be prepared by projecting on the melted regulus small pieces of phosphorus. In this case, however, the crucible must be removed from the fire immediately after the last portions are thrown in, otherwise by a continuance of the heat it would be all volatilized.

The phosphurets of antimony are not applied to any use, and the above are all the facts which we are possessed of concerning them.

§ 11. *Alloys of Antimony.*

1. *Antimony with gold.* See GOLD.
2. *Antimony with platina.* See PLATINA.
3. *Antimony with silver.*

According to Lemery, one ounce of reguline antimony and three drams of cupelled silver, being fused together in a strong heat, yielded an alloy of the same weight as the original materials, and similar to common regulus of antimony, but more compact, and not so brittle. Gellert (*Chymie Metallurg.*) relates, that 181 grains of silver being fused with 255 grains of reguline antimony, the alloy was found to have lost during the process 115½ grains; the remainder was very brittle, and in colour similar to regulus of antimony: its specific gravity was = 8.44. But the sp. gr. of the silver being = 9.1, and that of the antimony being = 6.7, the sp. gr. of the alloy, supposing the whole loss of weight to have been antimony, ought to be = 7.56. Therefore the sp. gr. of this alloy is greater than the mean of its constituent parts. It is made no use of.

4. *Antimony with copper.*

These two metals mixed together in nearly equal proportions, form a hard brittle alloy, of a violet colour internally, which is not very soon affected by exposure to the air. Gellert, having mixed together 314 grains of copper, sp. gr. = 8.7, with 464 grains of reguline antimony, sp. gr. = 6.7, obtained an alloy whose sp. gr. was = 8.02. During the fusion there was a loss of 43½ grains; and putting the whole of this to the account of the antimony, the sp. gr. of the alloy ought, by calculation, to have been = 7.49. The sp. gr. therefore of this alloy is greater than the mean of its constituent parts. It is made no use of.

5. *Antimony with iron.*

The general properties of antimony with a very small proportion of iron, or *martial regulus*, may be found above in § 4. Gellert having mixed by fusion 115½ grains of iron, sp. gr. = 8.0 with 173 grains of reguline antimony, obtained an alloy of 63 grains less by weight than the materials. It was brittle, of an ash colour, and contained specks like rust of iron. Its sp. gr. was = 6.92. Now supposing the loss of weight to be placed to the account of the iron, the density of the alloy ought to be = 7.05; its sp. gr. therefore is less than the mean of its ingredients. This alloy was wholly unaffected by a powerful magnet, except one or two particles which appeared to be iron. It is not made any use of.

6. *Antimony with mercury.* See MERCURY.

7. *Antimony with tin.*

These two metals being mixed together in nearly equal proportions, form a moderately hard, very brilliant, and brittle alloy, capable of receiving an exquisite polish, and not easily tarnished; it has therefore been occasionally manufactured into speculums for telescopes. Gellert mixed together by fusion 231½ grains of tin, sp. gr. = 7.36, with 231½ grains of antimony; 77 grains were lost in the process, and the alloy was = 6.94 sp. gr. Supposing the whole loss to

be attributed to the tin, the density of the compound ought to be $= 7.0$; its sp. gr. is therefore less than the mean of its ingredients.

8. *Antimony with lead.*

This is the most important of all the alloys of antimony, it being the material of which the common types for printing are made. In proportion as the lead exceeds the other ingredient, will be the ductility of the mass; and the lead may be hardened, and its fusibility unimpaired by so small a proportion of antimony as not to injure its ductility. Gmelin found that equal parts of the two metals produced a porous brittle alloy; one part antimony, and two lead, afforded a more compact metal, but still brittle; one part antimony, and three lead, gave a homogeneous metal, ductile under the hammer, and much harder than lead: one part of antimony gave to eight of lead an increase of fusibility, hardness and colour, without materially injuring its malleability. According to Gellert, 386½ grains of lead, sp. gr. 11.7, being fused with 333 grains of antimony, experienced a loss of 101 grains. The alloy was brittle, and presented a granular somewhat shining fracture; its sp. gr. was $= 9.17$; and even if the whole loss of weight is attributed to the antimony, the density by calculation ought to be $= 9.12$. The mass is therefore of a greater sp. gr. than the mean of its ingredients.

9. *Antimony with zinc.*

Equal parts of the two metals being fused together, formed a homogenous brittle mass of a light ash-colour; the loss of weight was about one-sixth of the whole; as however both these metals are very volatile, it is impossible to say with any certainty what proportion of the loss is to be attributed to each; the sp. gr. of the mass was rather less than that of the antimony, which is the lightest of the two. It is not used.

10. *Antimony with bismuth.*

According to Gellert, equal parts of the two metals being fused together, lost $\frac{1}{20}$ of their weight, and produced an alloy of a lighter colour than bismuth, and very brittle, displaying in its fracture a cubical structure like that metal; the sp. gr. of the mass was $= 8.96$; whereas, supposing the $\frac{1}{20}$ of loss to have been sustained by the bismuth, the heaviest of the two, its density by calculation ought to have been only $= 7.94$. Not used.

Concerning the combination of the other metals with antimony nothing is as yet known, except merely that cobalt unites easily with antimony, and manganese with great difficulty, and very imperfectly.

§ 12. *The medicinal Virtues, and pharmaceutical Preparations of Antimony.*

This metal affords several of the most valuable articles of the pharmacopœia; and as it has for so many years engaged the attention of chemists and alchemists (of whom a large number have ever been zealous to add to the resources of the healing art), we possess an almost infinite variety of antimonial preparations, all of them valuable as medicines, all enjoying many virtues in common, but a few out of the number recommending themselves peculiarly to the medical practitioner from the uniformity of their composition, or from a greater tendency to one mode of operation, rather than another, whereby particular indications in the cure of diseases may be fulfilled.

The first and most unquestionable operation of antimony on the human body is that of an emetic. This operation appears to be always in direct proportion to the activity of the antimonial in every other respect; and it exists in the highest degree in those preparations that are almost too virulent

to be given internally with safety in common cases. Antimonials excite to vomit very speedily, and their action is continued on the stomach for a considerable time; hence they are of a peculiar service, either where any acrid or poisonous matter has been taken which requires to be speedily and effectually removed; or in such cases as incipient fever, where, along with the clearing of the first passages, the physician wishes to prolong the mechanical action of vomiting, so as to induce a relaxation on the skin, and complete perspiration.

The operation of antimony is also extended to the intestinal canal, and hence it proves considerably purgative; and this effect takes place, either when the dose has been greater than necessary, merely to produce vomiting; or when the stomach has escaped the action of this powerful mineral. In order to secure the purgative, and prevent the emetic operation of antimony, it is advisable to unite it with some of the usual aperient medicines, whose operation it will thus assist in a considerable degree.

Antimony appears to promote almost all the excretions, and to quicken and stimulate the action of the absorbent vessels. It is therefore eminently diaphoretic (or promoting perspiration); expectorant, and often diuretic. It frequently happens that a single one of the antimonial preparations may be made to produce each of these effects by varying the dose, increasing it to render it a vigorous emetic or cathartic; and diminishing it when the gentle and more gradual operation of a diaphoretic or expectorant is to be secured.

A long continued course of antimonials, in the mildest form, wherein the direct operation of this metal is scarcely at any one time to be detected, has been found of essential service, both in various obstinate cutaneous complaints, and to produce that change of constitution and supposed resolution of internal obstruction, which entitle a medicine to the (somewhat ambiguous) character of alterative and *deobstruent*.

We shall now proceed to take notice of those preparations of antimony which are actually in use, or which have acquired a certain reputation in medicine.

Antimonium preparatum (Pharm. Lond. & Edin.). This is nothing but the crude antimony or native black sulphuret, prepared for medicinal use simply by triture to an impalpable powder, edulcoration with water, and subsequent drying. In this native mineral the proportion of the sulphur to the metallic part is so large, as to render it almost entirely inert, at least with regard to any sensible operation. It is sometimes, however, though rarely, employed in cutaneous complaints; and formerly it was used in the preparation of decoctions of sarsaparilla, guaiacum, and the other sudorific woods; a quantity of the mineral being tied up in a loose cloth, and suspended in the vessel in which the decoction was preparing; but as scarcely the minutest portion of the antimony could be dissolved by this process, it has properly been omitted.

The crude antimony, still, however, is retained in veterinary practice; and it may be given to many animals in doses of several ounces without any apparent operation.

It is likewise the material from which all the other antimonial medicines are prepared, directly or indirectly.

Antimonium vitresadum (Pharm. Lond.), *vitrum antimonii* (Pharm. Edin.), Glass of antimony.

To prepare this, the crude antimony is roasted on a tile or other shallow vessel, with a very slow fire, and frequent stirring, till all the sulphur is expelled which can be separated in this method. What remains is a grey powder, which is to be melted in a crucible and an intense fire into a yellowish vitrescent mass, to be poured out on a warm copper or iron plate, and when cold reduced to a very fine

powder. This preparation is an oxyd of antimony not at its highest point of oxydation, and still retaining a small portion of sulphur, which it is impossible to separate by mere heat. When well prepared it is pretty uniform in its nature, and is a very violent medicine, operating even in small doses as a strong emetic and cathartic. It is scarcely ever employed internally, but is the basis of the emetic tartar, and the antimonial wine, in the London Pharmacopœia.

Vitrum antimonii ceratum (Pharm. Edinb.).

Take one ounce of glass of antimony in fine powder, add it to one dram of yellow wax melted in an iron vessel, heat them gently together for a quarter of an hour, with constant stirring; pour out the mass when cold, and reduce it to powder.

The glass of antimony here incorporates with the wax, and changes its colour from lemon yellow to brown in the process. The wax appears to lessen in a very great degree the activity of the antimony, so that this medicine may be given with safety, and has been much recommended in dysenteries and other bowel complaints. It is rejected from the London pharmacopœia; but retained in those of Edinburgh, Amsterdam, and some others.

A great variety of preparations have been made from the crude antimony by the intermedium of nitre. The operation of this salt on the metallic sulphuret when dephlagrated together, is first to consume the sulphur, and afterwards, if the quantity be sufficient, to oxydate the metal to the highest point. It is remarkable, that the perfect oxyd of antimony, entirely divested of sulphur, and fully saturated with oxygen, appears almost as inert as the crude sulphuret of antimony itself, whilst in the intermediate states of desulphuration, and oxydation, many very active medicines are found.

Of these the two following alone are now retained, the first with a smaller proportion of nitre, the latter fully saturated.

Crocus antimonii (Pharm. Lond. & Edin.). Crocus of antimony, also called crocus metallorum, safran des metaux, and hepar or liver of antimony, by foreign writers.

To prepare this, take one pound of crude antimony, one pound of nitre, and one ounce of common salt, mix them accurately, and project them, a spoonful at a time, in a large crucible heated red hot; when the whole is dephlagrated, increase the fire so as to melt the mass, and pour it out. When cold it will be found to consist of two parts, the upper a whitish saline scoria, to be separated from the lower, which is the crocus of antimony. This is to be rubbed to a fine powder, and repeatedly washed with warm water, till it comes off from the powder quite insipid.

The crocus of antimony is a very violent emetic and purgative, and is seldom employed internally except in farriery. When washed it appears to have the greatest resemblance to the glass of antimony above described, and it is reserved for similar purposes, that is, as a basis for the tartar emetic and some other of the antimonial preparations.

When prepared in the large way, it would appear that it is not necessary to heat the vessel in which the mixture is fired, the heat excited by the dephlagration being sufficient to fuse the whole to the requisite degree. The whitish scoria here produced consist of sulphat of potash (formed by the potash of the nitre and the sulphuric acid, generated by the dephlagration of the sulphur), of the sea-salt, and probably of a portion of uncombined alkali, with some particles of the metallic sulphuret that may have escaped the action of the nitre.

Antimonium calcinatum (Pharm. Lond.), antimonium

ustum cum nitro (Pharm. Edin.), calx antimonii, or diaphoretic antimony.

This is prepared, according to the London college, by projecting gradually in a hot crucible a mixture of one part of crude antimony with three parts of nitre, raising the heat after dephlagration, and continuing it for half an hour; and when cold, pulverizing andedulcorating it.

The Edinburgh college direct one part of the grey powder left after roasting crude antimony for the glass of antimony, to be dephlagrated with only an equal weight of nitre, to be heated for an hour; and afterwards reduced to powder and washed till insipid.

These two preparations are, however, essentially the same, and consist of the oxyd of antimony left after the sulphur has been entirely dissipated by the nitre, itself having been oxydated to a high degree by the same dephlagration.

As the intention of using so much nitre in the first method is to consume the whole of the sulphur as well as to oxydate the metal, it is obvious that a much less quantity of this neutral salt will be sufficient where so much of the sulphur has been driven off by roasting, as is the case in the second method. Formerly a distinction was made between the pulverized oxyd taken before, or after washing; in the first instance being termed *antimonium diaphoreticum nitratum*; and in the second, *antimonium diaphoreticum lotum*; the former, as it contained an alkaline salt, was deliquescent to a certain degree, and required to be preserved in a close vessel. It is now, however, disused, the *washed* alone being retained.

The diaphoretic antimony, owing probably to its high state of oxydation, is mild in its effects, and may be taken in large doses, without producing sickness or purging. It is naturally white and in a pulverulent state, the antimonial oxyd not being truly vitrified in the process, as it is in the preparation of the crocus of antimony, but only involved in the alkali of the nitre, from which it is separated by washing.

The several washings of this substance contain a mixture of sulphat of potash, with part of the nitre undecomposed, and the naked alkali, all holding in solution a certain quantity of antimonial oxyd.

If this compound liquor is decomposed by an acid, the metallic oxyd precipitates in the form of a white powder, which has been called the *cerusse of antimony*, or *materia perlata*; but if the liquor is merely evaporated to dryness, part of the salts crystallize together with metallic oxyd, and form the *nitrum sibiatum*, or *antimoniated nitre of Stahl*. These latter preparations are now in disuse.

Some other antimonial medicines have been prepared with different proportions of antimony and nitre, forming oxyds, all of which act in a similar manner upon the human body, but with different degrees of energy. It should seem that the middle point with regard to the proportions of antimony and nitre, that is, equal parts of each, furnishes the most active antimonial oxyd, which is the crocus; and the medicinal power seems to diminish in proportion as either of these ingredients is used in excess. Thus the completely oxydated metal, the diaphoretic antimony, is possessed of but little activity; and on the other hand, the *crocus antimonii medicinalis*, formed by dephlagrating eight parts of antimony with one of nitre, and consequently but partially desulphurated, is equally mild in its operation.

The *crocus antimonii mitior*, the proportions of which are two parts of antimony to one of nitre, is another medicine now in disuse, which appears to be more active than the last mentioned, but milder than the common crocus.

The *emeticum mite antimonii* of Boerhaave is made by employing one part of antimony to two of nitre, and is a mild and safe medicine.

Another antimonial oxyd, formerly employed in medicine, is prepared by dephlagrating the *regulus* of antimony with twice or thrice its weight of nitre, and this has also been termed by some the *cerussa antimonii*.

The nitre here, having no sulphur to engage it, acts entirely on the metal, and reduces it to the state of a perfect oxyd, which, when washed, resembles in every respect the washed diaphoretic antimony made with the black sulphuret and three times its weight of nitre. The *regulus*, however, does not require more than its own weight of nitre for this preparation; all the rest is superfluous.

Regulus antimonii medicinalis, vel *febrifugum Craanii*, an antimonial remedy much recommended by many of the German physicians, and introduced in the former pharmacopœias of Edinburgh, Brandenburg, Strasburg, and others of celebrity, but now disused.

This, which is improperly termed a *regulus*, is prepared by fusing together five parts of crude antimony with four of common salt and one of salt of tartar. On cooling, two substances are found in the crucible, an upper scoria, containing the sea-salt, the alkali, and part of the sulphur, and the lower, a reddish mass composed of the greater part of the metal, deprived of a portion of its sulphur by means of the alkali, and thus rendered more active as a medicine than the crude antimony. It is this lower reddish mass which is the *medicinal regulus*. The use of the common salt seems to be merely to assist the fusion.

Regulus antimonii. The methods of preparing the true *regulus* of antimony have been already mentioned. This metal used formerly to be cast in the form of a cup, and, owing to its slight degree of solubility in various menstrua, a powerful emetic liquor was prepared simply by filling the cup with wine, and suffering it to stand for some hours. At the same time the cup had lost so little of its weight that it would continue to give the same properties to fresh portions of wine for years, or almost centuries, without being corroded through.

In like manner the *regulus* cast into the form of pills would produce the emetic or purgative operation to any number of persons in succession, and hence they were called *perpetual pills*.

These preparations are now, however, discontinued.

Vinum antimonii. (Pharm. Lond.) Instead of the *regulus*, the glass of antimony is now employed as the basis of this medicated wine. One ounce of this, in fine powder, is to be digested for twelve days with frequent agitation, in a pint and a half of white Lisbon wine.

This is a very valuable antimonial, principally employed in doses of from ten to sixty drops as a diaphoretic. The quantity of the metal taken up by the wine is extremely small, but is liable to vary in proportion to the acidity of this menstruum, which is one inconvenience attending its use.

Vinum antimonii tartarificati. (Pharm. Lond. and Edin.) In the former dispensatory it is directed to be made by dissolving forty grains of emetic tartar in two ounces of boiling water, and afterwards adding eight ounces of white Lisbon wine.

In the latter, twenty-four grains of emetic tartar are simply dissolved in a pint of the wine.

The nature and preparation of the celebrated *kermes mineralis*, or *pulvis carbussianus*, have been already explained; this is at present laid aside, and in its place the London and

Edinburgh pharmacopœias have adopted the precipitate, formed from a liquid solution of sulphuret of antimony in caustic alkali, by the addition of an acid, instead of by mere cooling, as is the case with the *kermes*: this is the *Sulphur antimonii precipitatum vel auratum*, the golden sulphur of antimony.

To prepare it, boil for three hours two pounds of crude antimony with four pounds of the aqua kali puri (or caustic lye), diluted with three pounds of distilled water; strain it while hot through a linen cloth, and immediately add gradually dilute vitrollic acid, sufficient to precipitate the sulphurated antimony, which is of a fine golden colour. Wash it well with warm water, and dry in a gentle heat.

The golden sulphur is of a lighter colour than the *kermes*, the latter being generally of a brown or brick red. Both of them consist principally of sulphur, but holding in solution a certain quantity of the metal which renders them emetic or purgative when taken in doses of several grains. The golden sulphur is never used with a view of acting violently or by any sensible operation, but it is employed (often combined with mercury) as a gentle alternative, with a view of keeping up a constant perspirable state of the skin, and determining a gentle increase to the several emunctories. Hence its use in various obstinate cutaneous complaints, and other chronic disorders.

The only solutions of antimony in acids employed in medicine are the *muriated antimony*, more commonly known by the name of *butter of antimony*, and the *antimoniated tartrate of potash*, or the *tartar emetic*. The chemical nature of each of these interesting preparations has been already described.

The *muriated antimony* is much too acid and violent to be employed for internal purposes. It is used externally as a caustic, especially in farriery. The *powder of algaroth*, or the antimonial oxyd, precipitated from this salt by water alone, or by an alkaline solution, is used by several chemists as the basis of the emetic tartar.

Antimonium tartarificatum vel tartarus emeticus. (Pharm. Lond. and Edin.) To prepare this most valuable medicine according to the London Pharmacopœia: take one pound and a half of crocus of antimony in fine powder, two pounds of cream of tartar, and two gallons of water, boil them together in a glass vessel for a quarter of an hour, strain the liquor through paper, and set it by to cool: the crystals that form are the emetic tartar.

The Edinburgh college directs: first, to add some of the *muriated antimony* to hot water, holding salt of tartar in solution, to collect the white precipitate thus formed, and edulcorate it thoroughly: next to add nine drams of this precipitate, and two ounces and a half of cream of tartar, in fine powder, to five pints of water, and to boil the whole till the tartar is dissolved; afterwards to evaporate the liquor in a glass vessel, till a pellicle appears on its surface, and to set it by to crystallize.

The emetic tartar is by much the most valuable of all the antimonial preparations; its composition renders it sufficiently soluble in simple menstrua, and as it is almost entirely insipid, and as the requisite dose is in all cases comparatively small, it may be given with great ease to children, or wherever there would be a difficulty of getting down bulky medicines. In doses of from one to about three grains it proves emetic, and often purges even after the stomach has been emptied: in smaller quantities, or mixed with various other medicines, and especially with those that correct its emetic property, it fulfills the other intentions with which antimonials are given; and with proper precautions it is always safe, manageable, and highly to be depended on.

When prepared in the same way, it is generally very uniform in its nature, but it is liable to some variation, when different antimonial oxyds are used; an inconvenience it would be of great importance to prevent.

The last of the antimonial medicines that we shall mention, is the *pulvis antimonialis* (*Pharm. Lond.*), or the *antimonium calcareo-phosphoratum*. (*Pharm. Edin.*)

To prepare it. Take equal parts of crude antimony and hartshorn shavings, mix them together, and throw them into a wide iron pan, heated fully red, and stir them constantly till they acquire an ash-colour; then take them out, reduce them to powder, fill a coated crucible with it, and lute over the top another crucible, inverted, and with a small hole at the bottom, to serve as a cover: then raise the fire gradually to a full white heat, and keep it in this state for two hours; when cold, take out the contents, reduce them to a most subtile powder, and it is the *pulvis antimonialis*.

This preparation is intended as a substitute for the JAMES'S POWDER, one of the most celebrated empiric medicines in this or any other country, the value of which has long been established by the most unequivocal testimony. We shall refer the reader to this article for an account of the ingenious analysis made by Dr. Pearson of this powder, and published in the Philosophical Transactions, whereby it is proved to be a mixture of an oxyd of antimony with the earth of bones, or calcareous phosphat; and hence the *pulvis antimonialis* has been employed as a substitute.

This preparation is given in doses of one to five or six grains, or even more, and is employed peculiarly in removing general fever, by means of perspiration. It is never intentionally given in such large doses as to prove emetic; but it is generally supposed, that the genuine James's Powder may be taken in larger doses than the antimonial powder, without exciting sickness.

We may add, that Mr. Chenevix, (in the Philosophical Transactions for 1801) has given the following ingenious method of preparing this medicine in the moist way, which removes every cause of variation which may take place whenever the oxyd of a metal so volatile as antimony is in certain states, is subjected to intense and long-continued heat. The following is the simple process: "Dissolve together, or separately, in the least possible portion of muriatic acid, equal parts of the white oxyd of antimony, formerly called algaroth powder (made by dropping the butter of antimony into water), and of phosphat of lime; pour this solution gradually into distilled water, previously alkalized by a sufficient quantity of caustic ammonia: a white and abundant precipitate will take place, which, well washed and dried, is the proposed substitute for James's Powder."

In this process, the antimony and the phosphat of lime are precipitated from their solution in muriatic acid at the same instant, the former by means both of the ammonia and the water in which it is dissolved, and the latter merely by this alkali. Hence, the inventor gives the useful caution to pour the mixed muriatic solutions into the alkaline liquor, and not to add the latter to the former; in order that the precipitation of the antimony and the phosphate of lime may

be contemporaneous, and therefore in uniform proportion from first to last. The muriatic acid simply dissolves phosphat of lime, and does not decompose it, and therefore it is separated unchanged from its solution by the ammonia. If it be wished to prepare this powder with a stronger dose of antimony, it is only requisite to increase the proportion of muriated antimony to the muriated calcareous phosphat, before the precipitation is made.

We shall only add to this short review of the various antimonial preparations used in pharmacy, that several other preparations, slightly varying from those which we have mentioned, have been at times recommended by several eminent men, and have had a certain vogue; but it does not appear that any thing further can be expected from any other change in the preparation of antimonial medicines; and those which we already possess, form some of the most valuable articles of the *Materia Medica*.

§ 13. Uses of Antimony.

The uses of antimony are not very numerous; it is of high value in medicine, and is employed, in combination with other metals, in the manufacture of printers' types, and specula for telescopes. Its oxyds are used in colouring glass; the sulphuret is employed in scorifying copper and other metals which are found mixed with gold; hence it was called by the alchemists *balneum regis*, or *balneum solis*.

The native antimony, at first, was of service only in the composition of paint. Scripture describes it to us as a sort of paint, with which the women blacken their eye-brows. Jezebel understanding that Jehu was to enter Samaria, painted her eyes with antimony, or, according to the Hebrew, "put her eyes in antimony."

At this day the women of Syria, Arabia, and Babylonia, anoint and blacken themselves about the eyes; and both men and women put black upon their eyes in the desert, to preserve them from the heat of the sun, and the piercing of its rays. M. D'Arvieux tells us, that the Arabian women border their eyes with a black colour made of *tuty*, which the Arabians call *rebel*. They draw a line of this kind of blacking without the corner of their eyes, to make them appear larger. Isaiah, in his enumeration of the several ornaments belonging to the daughters of Sion, has not forgot the needles which they made use of in painting their eyes and eye-lids: nor has this practice escaped the lash of Juvenal.

"Ille supercilium madida fuligine tinctum
Obliqua producit acu, pingitque tremantes
Attollens oculos."

Ezekiel, describing the irregularities of the Jewish nation, under the idea of a debauched woman, says, that she bathed and perfumed herself, and that she anointed her eyes with antimony. Job shews sufficiently how much antimony was in esteem, by calling one of his daughters a vessel of antimony, or a box to put paint in, *cornu sibi*. Tertullian and St. Cyprian have declaimed very warmly against this custom of painting the eyes and eye-brows.

Arabic Gum

ARABIC gum, *gum Senegal*, *gummi Arabicum*, *Acacia vera succus*. This valuable article of commerce is a very pure concrete mucilage, which exudes from the *Mimosa Nilotica*, or *Acacia Vera*, a tree that grows abundantly on the sandy soil of Egypt and Arabia, on the banks of the rivers Senegal and Niger, near the Cape of Good Hope, and in several other parts of Africa. The fruit of the same tree also yields another mucilaginous juice, but at the same time considerably astringent, and of a brown colour, which has been already mentioned under the article ACACIA.

The purest gum arabic is brought in caravans to Cairo by the Arabs of the country around mount Tor and Sinai, who bring it from this distance on the backs of camels, sewn up in bags of skin, and often adulterated with sand and other matters.

The settlement at Senegal is another great mart for this commodity; and the gum, which bears the name of this place, is generally in larger masses, and of a yellowish or amber colour, but it does not sensibly differ from the Egyptian gum in any of its properties.

This mucilage exudes spontaneously in a liquid state from the trunk and boughs of the tree, and hardens by contact with the air and the heat of the sun. It begins to flow about December, immediately after the rainy season, near the flowering time of the tree. Afterwards as the weather becomes hotter, incisions are made through the bark, to assist the transudation of the juice.

The best gum arabic is brought over in oblong or roundish lumps seldom bigger than a walnut, nearly transparent, white, or of a pale yellow, wrinkled, and of a shining fracture. It is so brittle as easily to be reduced to a fine powder. It is also perfectly insipid and inodorous, dissolving in the mouth into a clammy liquid.

As the gum arabic is the most perfect specimen of a *GUM MUCILAGE*, all the properties which we shall now mention to belong to it, may be considered as descriptive of this whole class of chemical substances.

The habitudes of this gum with water affords one of its most striking characters. When added to water, either cold or hot, and not less than twice its weight, it dissolves slowly, and converts the whole into a very slimy viscid liquor. Heat does not coagulate this solution; a gentle evaporation will expel the water and leave the gum as solid and brittle as before, equally resolvable in water, and unaltered in any of its properties. In this respect it differs in a striking manner from most other vegetable substances.

It is entirely insoluble in ardent spirit and in oils; alcohol indeed coagulates the watery solution, by uniting with the water, and thus precipitating the gum.

Gum mucilage is but little inflammable, when put into the fire it swells and grows puffy, and soon is reduced into a voluminous coal. Distilled *per se* in a retort, it first yields a limpid water, then an acid (which was at one time supposed to be peculiar, and was termed the PYRO-MUCOUS), and afterwards a thick empyreumatic oil, and a little volatile alkali, like all the distillations of vegetable matter.

The pure gum mucilages, when dry and solid, will remain unchanged for any length of time: the watery solution is likewise the least alterable of all the vegetable liquids; but by long keeping it becomes sour and grows mouldy on its surface, if it is prevented from drying up by the evaporation of its water.

When nitric acid is distilled off gum arabic, or any other of the gum mucilages, a peculiar acid is formed, which appears as a white powder of difficult solution, and has been termed the MUCOUS acid. It is the same with the SACCHAROLACTIC acid of Scheele.

The specific gravity of the solid mucilages, according to Fourcroy, is from 1.3 to 1.48.

The gum which exudes in considerable abundance in our own climates from the apricot, plum and cherry trees, bears the strongest resemblance to the gum arabic in all its properties, only it is generally of a yellower colour, not so brittle, and forms a mucilage of somewhat less tenacity.

Gum arabic is employed for a number of valuable purposes both in the arts and in medicine. It may be used either to suspend in water a number of substances which could not otherwise be kept equally diffused in this liquid, or as a means of glueing together a variety of articles of light work; and as a clean colourless cement perfectly easy of application, and which may be prepared in a few minutes, it is peculiarly valuable. Gum Senegal is used in very large quantities by the calico printers, to mix the colours and the mordants in block printing; gum arabic forms the basis of crayons, and the cakes of water colours, and of several liquid colours, of which common writing ink is a familiar example.

All the gum mucilages are considerably nutritious; in the countries where the gum arabic and senegal grow native, it forms an important article of food, either by itself, or mixed with milk, rice, &c. Hasselquist relates an instance of the travellers of a large caravan, who had consumed

all their provisions in the middle of their journey, preserving themselves from famine by the gum arabic which they were bringing as merchandise.

In medicine, this gum is employed, either by itself, or as a vehicle for other substances. Taken internally, it has been supposed to be incrassating and obtunding; qualities, however, which probably have little foundation in fact and real observation. As it is simply mucilaginous, it will certainly in some degree protect the parts with which it comes in contact from the effect of any acrid and stimulating substances; and thus it is of use in quieting the tickling cough which arises from any acrimony in the fauces, and in some cases it is of material service in diarrhoea and dysentery. It is given either in powder, or dissolved in water, almond milk, &c.; and one ounce of the gum is sufficient to give a considerable thickness to a pint of liquid, without making it too slimy to drink with pleasure.

In pharmacy, gum arabic possesses the valuable property of rendering miscible with water the balsams, resins, fixed oils, and similar substances, whereby they may be very com-

modiously taken in a liquid form. One part of gum arabic previously softened with water (or an equivalent quantity of the mucilage), will thus render four parts of balsam or oil soluble in any watery liquid, and will form an uniform emulsion. Even mercury may be thus suspended in water by being previously rubbed for a considerable time with gum arabic, which preparation is called, from the inventor, *Plenk's solution*. The corrosive acids, when taken internally, are best diluted with a solution of this gum.

The pharmaceutical preparations, in which gum arabic enters as a principal ingredient, are the *Mucilago gummi Arabici*, a simple solution of one part of the gum in two parts of boiling water; the *Emulso Arabica Ph. Edin.* which is gum arabic dissolved in almond milk; the *Trochisci Arabici*, with gum arabic, starch and sugar; and the *Pulvis tragacanthæ compositus Ph. Lond.* a powder made of tragacanth, gum arabic, starch, and sugar. *Murray Appar. Med. Fourcroy, &c*

Arkwright

ARKWRIGHT, SIR RICHARD, in *Biography*, an eminent manufacturer, advanced himself, by his mechanical inventions for carding and spinning cotton, from the humble station of a country barber to an immense fortune and an honorary title. For performing these operations of carding and spinning by means of machinery, it was required either that the usual manœuvre of the carder should be effected with square cards, or that cylinders, covered with a kind of metallic brush work, should be made to revolve in contact with each other, either to card or to strip, according as the respective velocities, directions, and inclinations of their wires might be adjusted. With regard to spinning, it would be indispensably necessary, not only that the raw material should be very nicely prepared, but also that it should be regularly drawn out by certain parts representing the fingers and thumbs of the spinner. The contrivance for this purpose consisted of a certain number of pairs of cylinders, each pair revolving in contact with each other. Suppose then that a loose thread or slightly twisted carding of cotton were made to pass between one pair of cylinders, properly adapted with a facing for holding it, and that it proceeded from thence to another pair, whose surfaces revolved with a much greater velocity; it is evident, that this quicker revolution would draw out the cotton, and render it thinner and longer when it came to be delivered at the other side. This is the operation which the spinner performs with his finger and thumb; and if the cotton be delivered to a spinning apparatus, it will be converted into thread. Sir R. Arkwright contrived to make these rotatory carding and spinning engines to move by horse, by water, and by steam; and thus, by the saving of labour, and with the advantage of a patent monopoly, he was rendered one of the most opulent of our manufacturers.

After he had quitted his original business, in the year 1767, he came to Warrington, where he projected a mechanical contrivance for a kind of perpetual motion. A clock-maker of this town, whose name was John Kay, dissuaded him from it, and suggested that much money might be gained by an engine for spinning cotton, which Kay promised to describe. Arkwright at first objected, but afterwards asked Kay, if this engine might be made at a small expence? Kay had been employed in making a cotton

spinning engine; and in the trial for setting aside Arkwright's patent, it was proved that he had invented such an engine, but he had not brought it to perfection. Kay and Arkwright applied to Peter Atherton, esq. of Liverpool, for assistance in the construction of such an engine, who, discouraged by the mean appearance of the latter, declined undertaking it; though he soon after agreed to lend Kay a smith and watch-tool maker to prepare the heavier part of the engine, whilst Kay himself undertook to make the clock-maker's part of it, and to instruct the workmen. In this way Arkwright's first engine, for which he afterwards took out a patent, was made. Mr. Arkwright soon after connected himself in partnership with Mr. Smalley of Preston in Lancashire; but their property failing, they went to Nottingham, and there, by the assistance of wealthy individuals, erected a considerable cotton mill turned by horses. A person of the name of Hayes had also employed himself in making cylindrical carding engines. Upon the whole, without minutely detailing further particulars, it appears that the cotton spinning was no new attempt when Mr. Arkwright embarked in it; but many difficulties occurred in bringing it to perfection. In the hands of Mr. Arkwright, the carding and spinning of cotton became a great national manufacture. According to his statement, it appears that the advancement of it during a period of five years, cost him and those that were concerned with him 12,000*l.* before they derived from it any profit; and it must be allowed, that he alone seems to have had sufficient perseverance, activity, and skill to perfect a scheme, in the prosecution of which many others had failed, and to render it valuable to himself and the public. The merits of sir R. Arkwright may be summed up with observing, "that the object in which he was engaged is of the highest public value; that though his family were enriched, the benefits which have accrued to the nation, have been incalculably greater; and that upon the whole, he is entitled to the respect and admiration of the world." He was knighted by his present majesty on the 22d of December 1786, on occasion of presenting an address from the high sheriff and hundred of Wirksworth; and died at his works at Crumford in Derbyshire, August 3d, 1792. Gen. Biog.

Arsenic

ARSENIC, *Arsenique*, Fr. *Arsenik*, Germ. *Arsenicum*, Lat. *Αρσενικον*, *Αρσενικον*, Theoph. & Dioscorid.

Arsenic is a brittle acidifiable metal, of a bluish white colour, easily tarnishing by exposure to the air: it does not melt, but volatilizes by a gentle heat, exhaling copious white fumes, with a peculiar alliaceous or garlic smell; it is soluble in nitro-muriatic acid, and is precipitable in the form of a light orange-coloured powder by sulphuret of ammonia, or of a green colour by ammoniated copper.

§ 1. Ores of Arsenic.

Besides the ores of arsenic properly so called, this metal is found in combination with silver, copper, iron, lead, cobalt, antimony, and lime, all of which will be treated of in their proper places: at present we shall confine ourselves to those substances which, by the common consent of mineralogists, are arranged as ores of arsenic.

Sp. I. Native Arsenic. *Arsenic testacée*, Born. *Arsenic natif*, Haüy and Brochant. *Gediegener arsenick*, Emmerling, &c. *Arsenicum nativum*, Werner. *Arsenicum nigrum*, *Cobaltum testaceum*, *Fliegenslein*, *Scherbenkobelt*, &c. of the older writers.

Its colour when newly broken is a very light lead-grey, often passing into tin white; but the surface, by a short exposure to the air, becomes yellow, then blackish grey, and finally almost black.

It is found generally in mass, more rarely disseminated; in kidney-shaped or clustered masses, or in plates, or carious, branched, bearing impressions, &c. Externally it is rough or granular, with little or no lustre; internally it is little shining, with a metallic lustre.

Its fracture is sometimes fine-grained, uneven, or curved lamellar; more rarely radiated or bundled. It flies when broken into indeterminate blunt-edged fragments, sometimes in the form of plates. It is also frequently composed of distinct concretions, either testaceous, concentric, or kidney-shaped.

It acquires a polish by friction, and emits an alliaceous odour; is half-hard and brittle. It rings when struck by a hard body.

Sp. gr. according to Briffon 5.724 . . . 5.763; according to Kirwan 5.67.

Before the blow-pipe native arsenic fuses without difficulty, giving out a copious, white, alliaceous fume; by an increase of heat it takes fire, burns with a bluish flame, and is wholly dissipated. It deposits on the charcoal, or any cold substance that is presented to it, a white powder, which is oxyd of arsenic.

Native arsenic is not, however, in a state of absolute purity; it always contains a small and variable proportion of iron; besides occasionally a little gold or silver.

This mineral is found at Wörlich and Joachimsthal, in Bohemia; at Freyberg, Annaberg, Schneeberg, Marienberg, and Johangeorgentstadt, in Saxony; at Andreasberg, in the Hartz; at Gröfberg and Seltspach in Carinthia; at Nagyag in Transilvania; and St. Marie-aux-mines in France. It occurs only in the veins of primitive mountains: the substances that accompany it are red silver, realgar, galena, native silver, specular cobalt, kupfernickel, spathose iron, fahlerz, pyrites, quartz, heavy spar, calcareous and fluor spar.

Sp. II. Marcasite or Mispickel. *Arsenical pyrites* Kirw. *Fer arsenical* Haüy. *Arsenik kies* Germ. *Arsenicum mineralizatum pyritaceum* Werner.

Of this there are two varieties.

Var. 1. Common Marcasite. *Gemeiner arsenik kies* Germ.

Its colour where recently fractured is silvery white, but in general its surface is yellowish, greyish, or bluish, sometimes iridescent. It occurs in mass, disseminated, investing, or crystallized. The primitive form of its crystals is a strait rhomboidal prism, the angles of whose base are $103^{\circ} 20'$ and $76^{\circ} 40'$: the other varieties that have been ascertained are, the rhomboidal prism with dihedral summits (*Fer arsen. ditetradre* of Haüy), and the same prism with tetrahedral summits (*F. ar. quadrioctonal* of Haüy). The lateral faces also sometimes cylindrical, either concave or convex. The faces composing the sides of the prisms are always smooth and shining; those of the summits are crossed by striae. Internally the marcasite is shining, with a metallic lustre. Its fracture is uneven, coarse, or finely granular; presenting occasionally columnar or granular distinct concretions. When broken it flies into indeterminate sharp-edged fragments. It is hard, generally giving fire with steel, and diffusing an alliaceous odour; is brittle, but difficult to break.

Sp. gr. according to Gellert 5.75; according to Haüy 6.52.

When exposed to the flame of the blow-pipe on charcoal, this mineral gives out a copious arsenical fume, and melts into a globule of brittle iron. Its analysis has not yet been made with any accuracy, and probably the amorphous kind at least, on account of the variable proportion of its ingredients, is incapable of affording an exact result. The constituent parts of pure mispickel appear to be only arsenic and iron, both of them in the metallic state: but it is often intimately mixed with iron pyrites, and hence affords an uncertain quantity of sulphur: two specimens analysed by Vauquelin, yielded respectively 38.8 and 4. per cent. of arsenic, which seems to shew that mispickel and pyrites, though, when pure and crystallized, sufficiently distinct from each other, are so intimately blended by nature, as to pass by insensible gradations from one to the other extreme of the series. In several of these compounds, however, minute inspection has discovered small separate cubes of pyrites; and these intermediate varieties are rather to be considered as simple mixtures than chemical compounds.

The two substances with which marcasite is liable to be confounded, are arsenical cobalt and pyrites. It differs from the first in being harder, in having a yellowish white tint, while the colour of the other is reddish white, and in the form of its crystals: it is distinguished from the latter by giving out when struck an arsenical, instead of a merely sulphureous odour, by the lighter yellow of its colour, and by its crystalline forms.

Marcasite is found in Bohemia, in Saxony, in Silesia, in Cornwall, and various other places, either in veins, or disseminated through primitive mountains. The substances by which it is accompanied, are generally tin-stone and galena; more rarely black blende, spathose iron, copper pyrites,

quaraz, fluor and calcareous spars. At Reichenbach in Silesia, it is found in serpentine rock.

Marcasite appears to be made little or no use of: the more brilliant specimens are occasionally cut and polished, and made into buttons, and other small articles; this is particularly the case with some found near Dublin, and called Irish diamonds.

Var. 2. Argentiferous marcasite. *Weisserz* Werner.

Its colour is similar to that of the preceding variety, but when exposed to the air it tarnishes to a deeper yellow. It is rarely found in mass, being generally disseminated or crystallized in minute acicular four-sided prisms. Externally it is shining, internally little shining, with a metallic lustre. Its fracture is fine-grained, uneven, with granular distinct concretions.

Its other external and chemical characters correspond with those of the preceding variety, from which it differs only in a variable proportion of silver, from 1 to 10 per cent.; and for which it is often worked.

It is found at Freyberg and Braunsdorf in Saxony; and is usually accompanied with common marcasite, red silver, galena, copper pyrites, &c.

For the affinities of this mineral with arsenical silver, see SILVER, *Ores of*.

Sp. III. Sulphurated arsenic. *Rauschgelb* Germ. *Arsenic sulfuré* Haüy. *Arsenicum mineralizat. risigallum* Werner.

This species is divided into two varieties, the red and yellow.

Var. 1. Realgar. *Rothes rauschgelb* Emmerling. *Arsen. min. risigall. rubrum* Werner. *Arsenic sulfuré rouge* Haüy. *Rubine d'arsenic, Sandarac, Rubin schwarzf.* &c.

Its colour is a bright Aurora red, passing on one hand to scarlet-red, and on the other to yellow-orange. It is rarely found in mass, more frequently disseminated or investing, and very frequently crystallized. The primitive form of its crystals is a long octahedron, with scalene triangular faces exactly the same as sulphur. The two pyramids of the octahedron are sometimes intercepted by a quadrilateral prism (see *Crystallographical Plates*, fig. 94.), forming the variety A. f. r. émouffé of Haüy: other varieties are derived from bevilling and truncating the angles of the intervening prism; and a further variety (fig. 95.) A. f. r. surcomposé of Haüy, is produced by the truncature of all the solid angles of the terminating pyramids. The crystals are for the most part small, and not easy to determine. Their surface and interior are shining or much-shining, with a vitreous lustre. The fracture is uneven granular, passing into minute conchoidal: the fragments are indeterminate, blunt-edged. It is commonly translucent, occasionally semi-transparent or opaque. The colour of its streak is orange-yellow. It is very tender, somewhat brittle, and easily broken by the nail. Sp. gr. according to Bergman 3.22. Brisson 3.33. It is idio-electric acquiring the resinous electricity by friction.

Before the blowpipe it melts easily, burns with a blue flame, and a sulphureous arsenical odour, and is for the most part volatilized. Nitrous acid in a short time deprives it of its colour. It has never been accurately analysed, but consists principally of arsenic and sulphur.

Realgar occurs native in the vicinity of Ætna and other volcanoes, and also in the primitive mountains of Germany, Hungary, and Switzerland. The substances that are found most frequently to accompany it are native arsenic, red silver, and galena.

The substances that it resembles are red silver and chromated lead; it may, however, be distinguished from the first by the following properties: the powder of the silver ore is red, that of the realgar orange-yellow; the sp. gr. of the

silver ore is the greatest, in the proportion of about 5 to 3; besides which, it does not become electric by friction, nor does it flame or volatilize by the blowpipe. Chromated lead is more than twice as heavy as realgar, and exhibits the same differences with regard to electricity and habitude before the blowpipe as red silver.

Native realgar is made no use of; for the purposes to which the artificial is applied, see § 12. of this article.

Var. 2. Orpiment. *Gelbes raufschgelb*, Emmerling. *Arsen. min. risgal. flavum*, Werner. *Arsen. sulf. jaune*, Haüy. *Auripigmentum*, Lat.

Its usual colour is a beautiful lemon-yellow, passing on one side into sulphur-yellow, gold-yellow, or honey-yellow, and on the other into aurora-red. It is found disseminated, and in mass. It is internally shining, or very shining, with a bright waxy lustre, sometimes passing into the metallic. Its fracture is straight or curved foliated. In mass it is rarely more than translucent at the edges, but in thin plates is semi-transparent. Its streak is of the same colour as the mineral itself, only a little lighter. It is very tender, soft to the touch; when in plates is flexible though not elastic. Sp. gr. 3.45. It is idio-electric, and in its chemical characters, corresponds with the preceding variety. It consists of sulphur and arsenic, but the proportions are not ascertained with accuracy.

Orpiment is found in the Bannat in Natolia and Servia, at Nagyag in Transylvania, Felsőbanya in Hungary, &c.

It appears to be a mineral of late formation, being always found in stratiform mountains. It is, for the most part, accompanied by clay, quartz, &c. &c. sometimes by realgar.

The crystalline forms that are usually attributed to this mineral are, upon the authority of Haüy, referred to the preceding variety.

Sp. IV. Native oxyd of Arsenic. *Arsenic oxydé natif*, Fr. *Natürlicher arsenik kalk*, Germ. *Arsenicum ochraceum album*, Werner.

Its colour is snow-white or yellowish, reddish, or greenish-white; it is found also of a clear smoke grey. Its common form is that of a superficial earthy friable crust on the surface of other minerals: more rarely it occurs in an indurated state, either stalactitic, clustered, or crystallized. The crystals are always extremely minute, sometimes capillary, bundled, interlaced, or diverging, sometimes in octahedrons, sometimes in quadrilateral tables. When crystallized it appears to be translucent, but in the earthy state it is always opaque. It is very tender, often friable, brittle; has a very sharp disagreeable taste. Sp. gr. 5.7.

Before the blowpipe it gives out a white smoke, and the usual arsenical odour; the grey coloured, as being little oxydated, burns with a bluish flame: after a time, but not so quickly as native arsenic, it is almost wholly volatilized. It is soluble in fifteen times its weight of boiling water: and appears to be an oxyd of arsenic nearly pure with a variable proportion of oxygen. The only substance with which it is liable to be confounded, is the Pharmacolite, or native arseniat of lime: this latter however is insoluble in water, and leaves a considerable residue when exposed to the blowpipe.

The native oxyd of arsenic is a mineral of very rare occurrence; it is found at Joachimsthal in Bohemia, in Saxony, Hesse, Transylvania, and Hungary, in the vicinity of native arsenic, and in certain cobalt mines.

Lenz, *verfuch der Mineralien*, vol. ii. p. 229. Kirwan's *Mineralogy*, vol. ii. p. 254. Haüy, *Traité de Mineral.* vol. iv. p. 220. Weidenmann, *Handbuch*, &c. p. 965. Brochant, *Traité de Mineral.* vol. ii. p. 435.

§ 2. Assay and Analysis of Arsenical Ores.

Arsenic is a metal in itself of so little value, and so noxious to other metals by its obstinate adherence to them, rendering them brittle, and debasing their colour, that in all works in the great, and even in almost all doctrinal assays, every method has been resorted to in order to drive off the arsenic, and its proportion to the whole mass has only been vaguely estimated by the loss of weight experienced during the process. The methods employed by Bergman, and the rest of his contemporaries, for ascertaining the quantity of arsenic in any of its ores, are extremely imperfect; even the accurate Klaproth confesses the imperfections of his mode, and till the publication of Mr. Chenevix's Analysis of the Arseniates of Copper and Iron, chemistry had attained no certainty in the resolution of this important problem. We shall first mention the advantages and defects of the methods recommended by Bergman, Kirwan, Klaproth, &c. and then proceed to the more accurate ones of Chenevix.

For the decomposition either of the *native arsenic* or *marcasite*, Bergman proposes to treat the pulverized ore with four times its weight of nitro-muriatic acid, formed of one part nitrous and one and a half or two parts muriatic acid. By this menstruum the silver will be converted into muriated silver, and will, together with the silica, remain undissolved, and the arsenic and iron will continue in solution. The filtered liquor is to be evaporated to one-fourth of its bulk, and poured into water; the arsenic will thus be precipitated, and the iron may then be thrown down from the filtered liquor by ammonia, &c. Another way of proceeding is to boil the ore with dilute nitrous acid, in order to take up the silver, copper, &c., while the arsenic will remain behind in form of a powder, and may afterwards be taken up by nitro-muriatic acid, and precipitated from its solution by water.

To these methods, however, it may be objected, 1st, That the precipitation of arsenic from its solution in nitro-muriatic acid by water, is denied by some chemists; and even if the fact of precipitation be allowed, still it is certain that some of the arsenic will remain in solution. 2dly, Antimony, which is often mingled with arsenical ores, will also be thrown down by this process. 3dly, The ammonia added to the remaining liquor, besides precipitating the iron, &c. will, by destroying the excess of the nitro muriatic acid, allow the arsenic acid to combine with the oxyd of iron, and thus induce an error in the proportion of this last metal. 4thly, It appears from the uniform experience of Klaproth, and other eminent chemists, that arsenic is abundantly soluble in nitrous acid, and that the silver precipitated from such a solution, even by muriat of soda, contains a little arsenic; and whichever of the alkalies was afterwards used for throwing down the copper, &c. the necessary neutralization of the nitrous acid would afford an opportunity for the arsenic acid to combine with the oxyd of copper.

The *native oxyd of arsenic* is proposed by Kirwan to be dissolved in boiling water, and of course its proportion is to be estimated by the loss of weight sustained by the quantity of ore thus treated. But (besides other objections) the dark-coloured varieties of this ore are probably not sufficiently removed from the metallic state, to be thus soluble. In order to decompose *realgar* or *orpiment*, Bergman directs long-continued ebullition with muriatic acid, adding, if necessary, a little nitrous, till the insoluble residue becomes grey. The insoluble powder is the sulphur, and the arsenical solution is to be decomposed as before mentioned by water. In this process, however, the sulphur will still retain some arsenic; and a little of the sulphur will be oxygenated, and converted into sulphuric acid. Mr. Kirwan

recommends to precipitate the arsenic from the muriatic acid by zinc; but, according to Mr. Chenevix, the precipitate is not pure metallic arsenic, but a mixture of this with arseniat of zinc.

The analyses in the dry way of the arsenical ores, are still less satisfactory than those in the humid way above recited. If sublimation in close vessels is had recourse to, a very intense and long-continued heat will be insufficient to volatilize the whole of the arsenic; the sulphur will also rise at the same time and produce orpiment. Roasting in a muffle, provided the ore is mixed with powdered charcoal, is more effectual; but in this case, not only the arsenic, but the sulphur and antimony, if there happens to be any in the ore, will fly off, and the relative properties of these must be estimated by mere guess.

Klaproth's method of treating the unfulphurated ores of arsenic, may be deduced from his analysis of the arsenical silver ore which consists of iron, arsenic, silver, and antimony. He first digests the ore with moderately strong nitric acid, which takes up the arsenic and the greatest part of the iron and silver: the addition of muriat of soda, throws down the silver in the state of muriat combined with a few atoms of arsenic; and afterwards the arseniat of iron is thrown down by potash; this precipitate being dried and weighed, is afterwards roasted with charcoal several times, till it ceases to give out arsenical fumes, and is attractable by the magnet: from the loss of weight sustained by the iron, the quantity of arsenic is then estimated. This however, as Mr. Klaproth himself observes, is a very imperfect method. Another way practised by him in the analysis of the arsenical cobalt is, to digest the ore in nitric acid, which oxydates the arsenic and takes up the greater part of it, leaving the residual arsenic soluble in water. The nitrous solution is then evaporated as long as it continues to deposit oxyd of arsenic, and the oxyd of cobalt afterwards separated by potash from the nitrous acid, is presumed to be pure because it affords a sympathetic ink with muriatic acid. From this humid analysis the cobalt ore is stated by Klaproth to contain 54.5 cobalt, 45 oxyd of arsenic and $\frac{1}{2}$ sulphur: a specimen however, of the same ore treated in the dry way, afforded only 44 cobalt; there was therefore required to make up the 100, $\frac{1}{2}$ sulphur, and 55.5 reguline arsenic. Hence it is evident, that little dependence is to be placed on the estimation of the quantity of arsenic from the oxyd precipitated by evaporation of the nitrous solution.

A more certain mode of ascertaining the proportion of arsenic, is furnished by Mr. Chenevix. Let the ore, previously reduced to extremely fine powder, be digested in nitric acid sufficient to acidify and take up the whole of the arsenic; pour off the clear liquor, and boil on the residue some distilled water; filter, and add the water to the nitrous solution: then neutralize the excess of acid by potash, taking care however, not to have an excess of alkali, and add nitrat of lead as long as any precipitate takes place: wash the precipitate in cold water, dry and weigh it. As the arsenical ores often contain sulphur, it is possible that the arseniat of lead thus procured, may be mixed with a little sulphat of lead: to decide this, digest the powder in some warm dilute muriatic or nitrous acid, and the arseniat of lead will be dissolved, leaving the sulphat behind. 100 parts arseniat of lead contain, of arsenic acid 33, oxyd of lead 63, water 4, and the 33 parts arsenic acid, denote 22 of the metal.

§ 3. Reduction of Arsenical Ores, and Preparation of Crude Arsenic, and White Arsenic.

Arsenic is a substance of such small value and such little demand, that none of the proper ores of this metal are

wrought in the great; the whole of the arsenic of commerce being prepared in Saxony, by roasting the cobalt ores in the manufacture of zaffre. These consist principally of arsenic, cobalt, iron, and a little sulphur; the first and last ingredients of which are got rid of by roasting: this process, instead of being performed in the open air, is done in an oven, the flue of which runs horizontally to a considerable distance before it bends upwards. By this contrivance the arsenic and sulphur when liberated, are for the most part deposited in the horizontal flue in the form of a greyish meal, streaked with yellow (such portions as are nearest the fire being often melted into a semitransparent crystalline mass). In this state it is called *crude arsenic*, or *flowers of arsenic*; the yellow streaks proceed from the sulphur uniting with the arsenic into orpiment: and besides this, it is also sullied with other impurities.

The *white arsenic* of commerce is prepared from the crude, by mixing this last with potash, or as some advise, with lime, and re-subliming. By this the sulphur and other impurities unite with the alkali, and the white oxyd is driven over into a heated receiver, where it melts into a heavy colourless transparent glass: by exposure for a short time to the air this glass becomes opaque, and resembles in its fracture the finest white china; and it is in this state that the white arsenic of commerce is found in our shops and laboratories.

§ 4. Preparation of Reguline Arsenic.

The old method of procuring the regulus of this metal, consisted in mixing white arsenic with half its weight of black flux, one fourth part of borax, and the same proportion of filings of iron or copper, and fusing the whole as quickly as possible in a crucible. When the whole is grown cold, there will be found on breaking the crucible, a mass of impure metallic arsenic, of a bluish white colour and considerable hardness and solidity. Probably this regulus was originally made from the crude arsenic, in which case the addition of iron or copper was for the purpose of separating the sulphur according to the process mentioned for martial regulus of ANTIMONY. (§. 4.—III.) It is obvious, however, that the arsenic must contain a variable proportion of iron or copper when prepared according to this method, by which its external and chemical characters will be in some degree modified. Another way of obtaining the regulus is recommended by Brandt, to which there can be no objection, upon the supposition that he used crude arsenic. He directs that white arsenic should be mingled with soap, and sublimed: in this operation the oil of the soap serves to de-oxydate the arsenic, and the alkali to keep down any portion of sulphur that may have been combined with the arsenic.

The white arsenic of commerce being an almost entirely pure oxyd of arsenic, the reduction of it into the metallic state is very easily effected. The most eligible way is to mix the white arsenic with any of the vegetable or animal expressed oils, till it becomes of the consistence of very soft glazier's putty; it is then to be made up into round or oblong pieces, and dropped into a Florence flask, so as not to adhere to the sides. The flask with its contents is to be put into a sand-bath, or over a gentle charcoal fire, and must be heated very gradually as long as any thick vapours proceeding from the decomposition of the oil are given out. When these cease, the heat may be by degrees increased till the bottom of the flask becomes obscurely red; shortly after the flask may be withdrawn from the fire, and when cold, upon carefully breaking it, there will be found in the neck and upper part of the vessel, a crust of brilliant triangular crystals of oxyd of arsenic, semi-transparent, and

of a yellowish grey colour, below these there will be a thick amorphous crust of regulus, and some impurities will remain at the bottom. Let these products, except the impurities, be separated from the fragments of glass, and pulverized together with half their weight of charcoal; then re-sublime the whole as before, and the inside of the flask will be found lined with a crust and crystals of pure and shining regulus of arsenic. It is necessary that these sublimations should be performed under a chimney, for the vapours that arise are intolerably fetid, and extremely noxious to the operator, bringing on in a very short time headache, sickness, and other unpleasant symptoms. Instead of a flask, an earthen retort may be made use of.

§ 5. *External Characters and physical Properties of Reguline Arsenic.*

The fresh surface of arsenic is of a bright metallic lustre, and a colour between that of tin and lead; it very soon however tarnishes by exposure to the air, becoming first yellowish, then slightly iridescent, and lastly black, in which state it is also wholly destitute of lustre. Its fracture is compact, granular; in hardness it is said to be superior to copper, but it is so brittle as to be reducible to powder in a common mortar without any difficulty, being neither malleable nor ductile. It crystallizes in octahedrons or tetrahedral pyramids. Sp. gr. = 8.31, according to Bergman, but according to Morveau = 5.76. It is not sensible to the smell when cold, yet the fingers after handling it acquire a slight metallic odour: it is manifest to the taste by a peculiar acid flavour; and when heated to volatilization, diffuses a characteristic fetid alliaceous odour.

§ 6. *Chemical Properties of Reguline Arsenic.*

I. *Effects of Heat.*

Arsenic, when pure, is incapable of being melted: in close vessels, at a heat inferior to that required for the fusion of tin, it begins to be volatilized, and is deposited in the upper and cooler parts unchanged in form or properties.

II. *Effects of Atmospheric Air.*

Atmospheric air at the usual temperature is slowly decomposed by this metal, the oxygenous part uniting with the arsenic, and converting it into a black oxyd, as mentioned § 5. At a heat of about 350° Fahr. the absorption of oxygen is much more rapid, and vapours of white oxyd begin to be visible, diffusing the well-known arsenical smell. At a higher temperature combustion takes place: thus if a vessel or crucible be made red hot, and a few pieces of arsenic be thrown in, a dense white vapour is immediately produced, accompanied by a light blue flame, and in a short time the whole is volatilized. This experiment must not be made in an iron ladle, for the affinity between the two metals at this temperature is so great, that artificial mispickel would be formed, and this being very fusible, the ladle would in all probability be found after the process to have a hole in its bottom.

III. *Effects of Water.*

Although arsenic is so easily oxydable, yet it does not appear capable of decomposing water; at least it may be immersed in it for any length of time without exhibiting any signs of solution or oxydation; and a covering of this fluid or of alcohol is the best preservative of arsenic against the tarnishing effect of the air.

IV. *Arsenic with Hydrogen.*

This combination was first discovered by Scheele. If liquid arsenic acid be digested with zinc, an effervescence will take place; and the air thus disengaged, has a strong arsenical smell, inflames by the contact of a candle, and deposits on the inside of the vessel a brown film, which is metallic arsenic. The same gas may also be produced by

granulated zinc in a hot solution of white arsenic in water with the addition of a little muriatic acid.

V. *Arsenic with Phosphorus.*

The union of these two substances was first observed by Margraaff, whose experiments have since been repeated and confirmed by Pelletier. Phosphuret of arsenic may be made in four ways: first, by subliming equal parts of phosphorus and white oxyd of arsenic, in which case, part of the phosphorus will be acidified at the expence of the metallic oxyd, while the remainder will combine with the metallic base; secondly, by subliming equal parts of reguline arsenic and phosphorus; thirdly and fourthly, in the humid way, by digesting equal parts of arsenic or oxyd of arsenic, with the same weight of phosphorus in a flask, containing a sufficient quantity of water. Phosphorated arsenic is volatilizable in a moderate heat, and is combustible on hot coals, exhaling the mixed odour of its ingredients.

VI. *Arsenic with Sulphur.*

Both arsenic, and the white oxyd, are capable of uniting with sulphur, by means of fusion or sublimation, into a beautiful red or yellow mass, according to the relative proportion of the ingredients. The yellow is called *orpiment*, or yellow sulphuret of arsenic, the red, *realgar*, or red sulphuret. The sulphur in the realgar is to the arsenic as 1 to 4 nearly, but in the orpiment as 1 to 9 or 10. Both preparations are fusible, and may be sublimed, but the realgar is more easily melted, and with care may be obtained quite transparent, and of a bright red colour; hence it has been called *arsenical ruby*, *rubine d'arsenique*. The sp. grav. of orpiment, according to Bergman, is = 5.315; but of realgar, only = 3.225.

These two substances have not been very accurately analysed, and it is the opinion of several modern chemists, that the differences between them does not depend so much on the proportions of the sulphur and arsenic, as on the presence of oxygen in the one, and its absence from the other. Hence they call realgar, sulphuret of arsenic, and orpiment, sulphurated oxyd of arsenic. This appears, however, to be a mistake, for the following reasons; when regulus of arsenic and sulphur are mixed together, the combination takes place without the extrication of any gas, but when the oxyd of arsenic is substituted for the regulus, at the moment of combination a portion of the sulphur is converted into sulphureous acid gas, probably on account of a decomposition of the metallic oxyd. Further, it appears from the experiments of Bucquet, that by continued fusion orpiment is made of a much redder colour than before, by the volatilization of part of its arsenic; and as an additional confirmation, it may be mentioned that realgar, being sublimed either with metallic or oxydated arsenic, is converted into orpiment.

It is not very easy to make realgar by the direct combination of its elements when they are in a state of purity, on account of the ease with which they are volatilized before they have experienced the proper degree of heat. In Saxony, where orpiment and realgar are made in large quantities, the method is to fill an oven like that described in § 3. with mispickel and iron pyrites, proportioning the quantities of each according as realgar or orpiment is intended to be produced. Now the sulphur and arsenic contained in these minerals being in natural combination with iron, require for their sublimation a degree of heat far greater than they could sustain without volatilization, if they were pure.

Sulphurated arsenic is wholly insoluble in water or alcohol. The nitrous and nitro-muriatic acids, especially when warm, take up the arsenic from the sulphur. The former of these,

however, except it is so concentrated as to act on the sulphur also, only takes up a portion of the arsenic from realgar, converting it into orpiment. Nitro-muriatic acid completely decomposes both the red and yellow sulphuret, hepatic gas being given out at the same time, a circumstance worthy of notice, as affording additional strength to the opinion mentioned above, concerning the state of the metal in these compounds. Sulphuret of arsenic is also decomposed by distillation with two or three times its weight of *corrosive muriat of Mercury*, the acid and oxygen of the mercurial salt uniting with the arsenic into corrosive muriat of arsenic, § 7.; and the metallic base with the sulphur of the orpiment, forming cinnabar.

In the dry way, the fixed alkalies decompose orpiment into alkaline sulphuret and arsenic, which latter sublimes; but if the alkali is in excess, the arsenic is in part detained as well as the sulphur. A solution of caustic potash in water being boiled with orpiment, dissolves it completely, but by the addition of an acid a yellow precipitate is thrown down, which probably is a *hydro-sulphuret of arsenic*. Quicklime and orpiment also unite by boiling in water, forming an arsenio-sulphuret of lime, which is sometimes employed as a *WINE-TEST*.

VII. Arsenic with Oils.

Any of the expressed oils being triturated with arsenic, gradually dissolve it, and thus acquire a dark colour and consistence like salve.

VIII. Alloys of Arsenic.

Arsenic unites with almost all the metals, debasing the red and yellow ones, and destroying in a great measure the lustre of all the rest, except tin. It renders those which are malleable and ductile, brittle, and for the most part increases their fusibility and hardness. For other particulars, see the several metals.

§ 7. Salts of Arsenic.

1. Reguline arsenic is acted upon by sulphuric acid when concentrated and assisted by heat: if the operation be performed in a retort with a pneumatic apparatus, there will be produced a considerable quantity of sulphureous acid gas, and sulphur will sublime into the neck of the vessel. What remains behind is a white mass similar to oxyd of arsenic, but combined with a little acid. By the addition of a fresh portion of sulphuric acid, the sulphated oxyd is taken up; as the liquor cools, however, a precipitation of crystalline grains happens, and these are *sulphat of arsenic*. This salt is much less soluble in water than white arsenic; when exposed to the flame of a blow pipe, it fuses and begins to emit an arsenical smoke, but requires a much longer time for its volatilization than the simple oxyd. By repeated cohobation with sulphuric acid, the arsenic approaches more and more to the nature of arsenic acid, but always continues in some degree sulphated.

2. Nitric acid when hot is readily decomposed upon reguline arsenic, being itself changed into nitrous gas, and the metal becoming oxydated. An addition of dilute nitrous acid at a boiling temperature effects a complete solution of the residual oxyd, and the liquor by evaporation and cooling may be brought to deposit crystals of *nitrat of arsenic*. This salt being abstracted with fresh nitrous acid, and then heated red hot, is wholly converted into arsenic acid. Nitrat of arsenic is sparingly soluble in water, and with the blow-pipe exhibits nearly the same appearances as the preceding salt.

3. Oxymuriatic acid when pure, fresh made, and in the form of gas, exercises a very powerful action on the regulus of arsenic, and exhibits a very striking and beautiful appearance. For this purpose, let a common six or eight ounce

phial be filled in the usual way with oxymuriatic acid gas procured from salt, manganese, and sulphuric acid, in order to have the acid as dry as possible (for the further securing of which, the gas produced about the middle of the process is the best); stop the mouth of the phial with a cork, and place it on a table in an upright position; then reduce some reguline arsenic to a fine powder, and cautiously opening the mouth of the phial, shake in from the end of a knife, or in any other convenient way, a little of the powder. As soon as it comes in contact with the gas, a white vapour will first appear, and will be immediately followed by ignition of the metal, which in its passage to the bottom of the vessel will appear like a stream of fire: this phenomenon may be repeated with successive portions of powder till the acid is almost wholly decomposed. At the bottom will be found a white acidulous oxyd of arsenic. Liquid oxymuriatic acid also is capable of dissolving reguline arsenic; but during this process, the metal being oxygenated at the expence of the acid, the result is muriat of arsenic.

4. Arsenic acid has a remarkable action on its own regulus, though the two appear to be incapable of combining into a proper salt. If the regulus is digested with the acid, its surface becomes shortly covered with a white powder, which is oxyd of arsenic. If the acid is kept in a state of fusion in a retort, and small pieces of the regulus are dropped in from time to time, an inflammation and sublimation of white arsenic will be manifest at each addition. Hence it appears that the oxygen of the arsenic acid quits this to combine with the regulus, till an equilibrium is produced by the one and the other being brought to a common state of oxydation.

These are all the acids which are known to act upon reguline arsenic, many others however are capable of combining with this metal, when previously brought to the state of white oxyd. The salts hence resulting we shall proceed to mention.

1. Muriatic acid when boiling will take up one third of its weight of oxyd of arsenic; a saline precipitate is produced by cooling, and if this is managed gradually, there are formed spicular crystals of *muriat of arsenic*. This salt sublimes wholly if exposed in close vessels to a moderate heat. Before the blow-pipe on charcoal it is decomposed in part and flies off, giving out at the same time the distinguishing odour of the metal. It is soluble, though sparingly, in warm water, and the solution is decomposable by an alkali, the oxyd of arsenic being thrown down.

Very dry and concentrated muriatic acid, or oxymuriatic acid, are capable of uniting with a much larger proportion of oxyd of arsenic than the liquid muriatic acid. This combination is called *butter of arsenic*, and is thus prepared: take one part of white arsenic, one and a half of red calcined sulphat of iron, and three parts of common salt; mix them accurately in a mortar, and distil in a glass retort from a sand bath. When the heat has been gradually raised so as to make the bottom of the retort nearly red, and nothing more comes over, the process is finished, and there will be found in the receiver two distinct liquors of different consistence. The lower one is of a clear iron brown colour, and is called *butter of arsenic*; the supernatant liquor is thinner, of a lighter yellowish colour, and is called *oil of arsenic*.

Butter of arsenic is a heavy thick liquor, excessively corrosive and poisonous; on exposure to the air it exhales a dense white suffocating vapour deliquesces, becomes turbid, and finally is spontaneously decomposed. When, instead of this gradual absorption of moisture, it is directly mingled with water, an immediate turbidness and precipi-

tation ensues of a white pulverulent matter, which was formerly taken for pure oxyd of arsenic; it still, however, as in the case with similar metallic precipitates, retains a portion of acid; for by heating in a close vessel, a little butter of arsenic is sublimed. Liquid muriatic acid unites very sparingly and imperfectly with the butter; and if considerably diluted with water, produces a decomposition just in the same manner as pure water does.

Oil of arsenic, like the preceding, is decomposed in part by water or alcohol, but the precipitate is not so copious: it mingles with liquid muriatic acid without producing any turbidness. The addition of a carbonated alkali is followed by effervescence and the precipitation of oxyd of arsenic. By spontaneous evaporation it yields crystals of muriated arsenic, and a slight efflorescence of white oxyd of arsenic.

There are several other methods of obtaining the butter and oil of arsenic: thus, if orpiment is distilled with two or three times its weight of corrosive sublimate, the sulphur of the former unites with the mercury of the latter, and produces cinnabar, while the arsenic of the former combines with the oxygen and acid of the latter into the oil and butter of arsenic. It is remarkable, however, that corrosive sublimate is not decomposable by oxyd of arsenic; for when the two are distilled together, whatever be their relative proportions, the mercurial salt rises unchanged. Indeed the superiority in affinity of muriatic acid for oxyd of mercury over oxyd of arsenic is still more strikingly shewn by distilling butter of arsenic with oxyd of mercury, in which case a little butter of arsenic first comes over, then corrosive sublimate, and finally white arsenic. If, however, *reguline arsenic* is distilled with corrosive sublimate, the produce is butter of arsenic, a little calomel, and running mercury.

Although the salts of arsenic have not yet received that notice from chemists to which they are entitled, still there has arisen some difference of opinion respecting the combinations of this metal with muriatic acid, some asserting the butter of arsenic to be a proper oxymuriat, while others consider it as scarcely differing, except in concentration, from the muriat. From a careful collation of the scattered facts relative to this subject, it appears that there is no such salt as oxymuriat of arsenic, but that muriatic acid, when its affinities are not weakened by water, will take up a large quantity of arsenical oxyd forming the butter of arsenic; that when by the gradual or sudden addition of water, the affinities of this latter are brought into action, an unequal partition of the acid and oxyd takes place into a soluble and insoluble muriat of arsenic. Hence we have three distinct salts composed of muriatic acid and oxyd of arsenic: first, muriat of arsenic with the smallest proportion of metallic oxyd, this is soluble in water and crystallizable by cooling, and is also capable of sublimation without decomposition; secondly, muriat of arsenic with a larger proportion of metallic oxyd (butter of arsenic), decomposable by water, and not crystallizable; thirdly, muriat of arsenic supersaturated with the oxyd, insoluble in water, decomposable by sublimation.

2. Oxymuriatic acid gas passed into an aqueous solution of white arsenic, is itself decomposed into muriatic acid; and by distillation, the water and muriatic acid being drawn off, there remains in the retort solid arsenic acid. It is therefore probable that the three muriats of arsenic just mentioned differ from each other in the degree of oxygenation of the metallic base, as well as in the proportions of it that they contain; the first being the least oxygenated, and the latter the most so.

3. Fluoric acid, when digested on white oxyd of arsenic, dissolves a small proportion; and by evaporation and cooling,

a granular crystalline salt is obtained, *fluat of arsenic*, the properties of which have not been examined into.

4. Boracic acid combines with white arsenic by means of water, but not in the dry way, according to Reufs. Equal parts of the oxyd and acid digested together in a little water are entirely dissolved, and afforded by evaporation *borat of arsenic* in powder or spicular crystals.

5. Phosphoric acid and oxyd of arsenic combine together without difficulty in the moist way, and afford crystals of *phosphat of arsenic*. This salt is very sparingly soluble in water, and is decomposable by heat, the oxyd being volatilized.

6. Liquid tartareous acid unites by digestion with oxyd of arsenic into a crystallizable salt, *tartrate of arsenic*; the properties of which are as yet in a great measure unknown.

7. Oxalic acid dissolves very easily a considerable quantity of white arsenic, and the liquor affords by evaporation and cooling prismatic crystals of *oxalat of arsenic*: these melt in a very gentle heat, the water of crystallization with part of the acid is evaporated, and the residue affords a very beautiful saline vegetation. Oxalat of arsenic is soluble both in water and alcohol, changes the colour of litmus tincture to red, and sublimates at a moderate heat; but at a higher temperature the acid is first destroyed and flies off, leaving behind the metallic oxyd.

8. Acetous acid, by long digestion and boiling with white arsenic, dissolves a small proportion, and deposits by cooling and evaporation small crystalline grains of *acetite of arsenic*, which are very sparingly soluble in water.

9. Benzoic acid, according to Trommsdorff, dissolves white arsenic with considerable ease, and forms with it *benzoat of arsenic*. This salt appears in the form of long slender radiating crystals, possessed of a sour and pungent taste, which effloresce in the air, are very soluble in boiling water, and are again for the most part deposited by cooling.

10. *Calat of arsenic* is not known, nor does the tincture of galls, according to the chemists of Dijon, produce any alteration in a solution of white arsenic.

11. Prussiat of potash, when pure, throws down an abundant white precipitate from the solution of arsenic in muriatic acid. This is soluble in a large quantity of water, and by sublimation in the dry way affords a semi-transparent mass; it is probably a *prussiat of arsenic*, but has been as yet scarcely at all examined.

The order of affinity of the various acids for oxyd of arsenic is not ascertained with much certainty. Bergman arranges them in the following order; muriatic, oxalic sulphuric, nitric, tartareous, phosphoric, fluoric, arsenic, acetic, and prussic acids.

§ 8. Oxyd of Arsenic, or Arsenious Acid.

Oxyd of arsenic is prepared in the large way according to the method already mentioned in § 3. When pure, it is of an opaque white colour; or if recently fused, is perfectly transparent and colourless. It crystallizes artificially (§ 4.) in three-sided pyramids, the vertical angle of which is generally deeply truncated; the crystals are transparent, of a dilute wine yellow colour, and not liable to effloresce or become opaque by exposure to the air, probably owing to their containing rather a smaller proportion of oxygen than the white arsenic of the shops. The sp. grav. of the fused oxyd is about = 5. It slowly excites upon the tongue a sweetish acid taste. It is the most volatile of any of the metallic oxyds, rising at 383° Fahr.

Pure water at the temperature of 61° Fahr. will dissolve about $\frac{1}{10}$ of its weight of this oxyd, but when boiling it takes up $\frac{1}{5}$, the greater part of which it retains even when cold; by evaporation, however, minute three-sided

pyramidal crystals are deposited: the solution is clear and colourless. Alcohol also, when boiling, will dissolve about $\frac{1}{10}$ or $\frac{1}{15}$ of its weight.

From many of its properties white arsenic seems to hold a kind of middle place between an acid and metallic oxyd: thus, it reddens litmus tincture, but turns syrup of violets green, and its aqueous solution is incapable of causing an effervescence in the carbonated alkalies and earths. In the new chemical nomenclature it is denominated the arsenious acid (*acide arsenieux*, Fr.); and the salts that are formed by its combination with the alkalies, earths, and metals, are called arsenites. These seem to hold nearly the same relation to arsenic acid and the arseniats, as sulphureous acid and the sulphites do to sulphuric acid and the sulphats.

The white oxyd of arsenic is easily deoxygenated by carbonaceous matter, by hydrogen, phosphorus, and sulphur, as already mentioned § 4. and 6. and is reduced to the state of reguline arsenic: its habitudes with acids are described § 7.

If to a solution of caustic pot-ash in water there be added some finely powdered oxyd of arsenic, the whole combines together by a boiling heat into a thick, viscid, scarcely fluid matter, of a brown colour, and nauseous smell, which as it cools becomes solid and brittle. This was named by Macquer *liver of arsenic*, and in the modern system has obtained the name of *arsenite of pot-ash*. By long exposure to the air it becomes deliquescent; it is readily soluble in water, but has not been made to crystallize. The addition of any of the acids to the solution causes an immediate decomposition with a copious precipitation of oxyd. Caustic soda produces the same general effects on white arsenic as potash, except that the arsenite of soda is crystallizable. Either of these salts, on being subjected to a full red heat, is decomposed; the greater part of the arsenic being volatilized in the form of a dense white smoke, while the remainder in the state of arsenic acid remains united with an excess of alkali. In the dry way, the white oxyd of arsenic melts together with the fixed alkalies, forming a mass not easily decomposable by heat. According to Bergman, potash is capable of thus fixing twice its weight of the oxyd, and soda three times its weight of the same.

When ammoniacal gas is passed two or three times over heated white arsenic, the two substances contract at length so intimate an union as to bear even fusion without separating from each other. In the moist way also, a combination takes place by the help of a gentle heat, which differs essentially from the common liver of arsenic in that the acids occasion no precipitation. These are singular facts, and the nature of the arsenite of ammonia is well worthy of more notice from chemists than it has yet obtained.

Quicklime and barytes combine by fusion with oxyd of arsenic into a vitreous mass which however becomes milky and opaque by the continued action of the air. In the moist way, lime and white arsenic being boiled together form a soluble arsenite of lime, from which a precipitate is thrown down on the addition of an acid. Neither magnesia, alumina, nor silica, appear capable of uniting with white arsenic by fusion, but all or any of them combine into an easily fusible mass with the arsenites of potash, soda, lime, or barytes.

But few of the neutral salts have been examined with respect to their action on arsenious acid. The nitrats of potash and soda are decomposed by heat converting the arsenious into the arsenic acid, and therefore this combination is treated of in § 10 (*Arseniats*). The effect of white arsenic on acetate of potash, as recorded by Cadet and the other chemists of the academy of Dijon, is however too

remarkable to be omitted. A mixture of these two substances being subjected to distillation, there first passed over a limpid liquor, with a slight arsenical smell; this changed the colour of syrup of violets red, caused an effervescence in a solution of carbonated alkali, and rendered the liquor turbid. The next product was of a reddish brown colour, and filled the receiver with a dense vapour of a most pestiferous odour, different however from that of arsenic; towards the end of the process, some reguline arsenic sublimed into the neck of the retort. The red liquor, after being confined for three weeks in a stopped phial, was still smoking, and exhaled the same detestable smell as before; it produced no alteration in syrup of violets, and occasioned only a very feeble effervescence with carbonated alkali, depositing a little flocculent sediment: it occasioned a white precipitate in a solution of corrosive sublimate: being poured into a filter, in order to separate a yellowish thick portion that had separated from the rest, scarcely had a few drops passed through, than a dense suffocating vapour began to rise accompanied by an ebullition at the edges of the vessel, and immediately followed by a beautiful rose-coloured flame which lasted several seconds.

A hot solution of arsenious acid dissolves some of the metals, particularly copper, iron, and zinc; the differences, however, between these and the metallic arseniats have not been ascertained with much accuracy.

§ 9. *Arsenic Acid.*

The properties of the white oxyd of arsenic that have been mentioned in the preceding sections, especially its ready solubility in water, its crystallizability, its taste, its habitudes with alkalies and metals, had long induced a suspicion of its saline nature. This suspicion was at length confirmed by Macquer's valuable discovery of the *arsenical neutral salt* (see § 10. arseniat of potash); but chemists still continued ignorant of the precise difference between this and the liver of arsenic (arsenite of potash). The illustrious Scheele first cleared up this difficulty, and pointed out a method of procuring the arsenic acid in a state of purity, and uncombined with any other substances. Bergman's valuable essay on the same subject confirmed and extended the discoveries of his friend and countryman, and more recent experiments have brought new accessions to the interesting facts already collected. Arsenic, as well as some others of the metallic bodies, is not only a combustible and oxydable, but also an acidifiable base. It combines with oxygen, in at least three different proportions. By the spontaneous action of air and moisture, at the usual temperature, it is converted into the black oxyd, an additional portion of oxygen is absorbed by the assistance of a higher heat, forming the white oxyd; and by means, that we shall now proceed to mention, this latter substance may be saturated with oxygen forming a perfect acid; the *arsenical*, or *ARSENIC* (*acidum arsenicum*, or *arsenici*, *acide arsenique*, *arseniksaure*).

The method recommended by Scheele for the preparation of arsenic acid is the following.—Take two parts of finely powdered white oxyd of arsenic, and put it into a capacious tubulated retort, adapted to a quilled receiver, and fixed properly in a sand-bath; then pour in seven parts, by weight, of strong and pure muriatic acid, and close the tubulure of the retort; as soon as the acid begins to boil, the arsenic will be rapidly dissolved; and when the whole is taken up, lower the heat, and add three and a half parts of concentrated nitric acid; the mixture will immediately begin to foam, and there will be a copious extrication of nitrous gas. The distillation is, at the same time, to be proceeding gradually, as long as any nitrous gas is produced; and when this ceases, one part more of the white oxyd of arsenic may

be added. As soon as this is dissolved, pour into the retort one and a half part of nitric acid, and a fresh effervescence will take place. The whole is now to be distilled to dryness, and towards the end of the process the heat must be increased till the bottom of the retort, with its contents, is red hot. After the retort is grown cold, it must be broken, and there will be found within it a saline mass, which is the dry arsenic acid. In order to preserve it in its solid state, it must be put into a dry, well-stopped phial. The proportion of acid thus procured is nearly equal to the quantity of white oxyd employed. The use of the muriatic acid in this process, seems to be merely that of a solvent of the arsenical oxyd, which is thus presented to the action of the nitric acid in a state of extreme division. The nitric acid is decomposed into nitrous gas and oxygen, the former of which flies away, while the latter is expended in acidifying the oxyd; by the subsequent red heat, the undecomposed residue of the nitrous acid, and the muriatic, are driven off in vapour, and the arsenic acid alone remains behind. It generally, however, corrodes the retort, in a greater or less degree; when the solid acid, when boiled with water, leaves a small insoluble residue of silice.

Bergman's method is to make a hot saturated solution of white arsenic in muriatic acid, and to add double the weight of nitric acid. The effervescence, however, thus occasioned, is so great, that a considerable portion of the arsenic is driven over in the form of butter of arsenic, and the consequent produce of acid is much diminished, the quantity of this being estimated by Bergman at no more than 80 per cent. of the white oxyd employed. Weigleb, by repeatedly returning the liquor collected in the receiver into the retort with fresh nitric acid, obtained $112\frac{1}{2}$ of arsenic acid for every 100 of oxyd.

Another method of preparing this acid, also discovered by Scheele, is by oxymuriatic acid. Take one part finely pulverized black oxyd of manganese, and mix it with three parts of strong muriatic acid, in a tubulated retort, large enough to allow ample room for the effervescence of the mass: the retort is to be connected, in the usual way, with a Woulfe's apparatus, containing the white oxyd of arsenic and a little water. By a gentle heat, the muriatic acid becomes oxygenated at the expence of the manganese, and passes into the bottles in the form of oxymuriatic acid; here it is decomposed, and the muriatic acid unites with part of the arsenic, while the oxygen combines with another portion. This compound liquor being then gently distilled to dryness, and towards the end of the process the bottom of the retort being made red hot, a complete separation will take place; in the receiver there will be found distilled muriatic, or butter of arsenic, and the saline mass remaining in the retort is arsenic acid.

A simpler way of procuring the acid, is to heat together the white oxyd of arsenic, with diluted nitrous acid, in a retort, and when the solution is complete, to add some strong nitric acid, and proceed to distillation: much nitrous gas will be given out, and some orange-coloured acid will come over into the receiver; return this upon the mass in the retort before it becomes dry, together with a fresh portion of strong nitric acid, and thus repeat the cohobation till the extrication of nitrous gas has almost ceased; then distil to dryness, and make the bottom of the retort red hot; all the remaining oxyd of arsenic and nitrous acid will be driven off, and nothing will be left behind but pure arsenic acid.

Besides the above processes, Pelletier has described another method of procuring the acid of arsenic. He mixes the white oxyd with nitrat of ammonia, and subjects the

mass to distillation in a luted retort. It is necessary to begin with a very gentle degree of heat, for the decomposition of the ammoniacal salt is otherwise so rapid, that a large portion of the oxyd of arsenic is carried over into the receiver. But by proper management, the operation goes on more slowly and quietly; there passes over some nitrous acid, and by a slight increase of the heat, ammoniacal gas is also produced; towards the end of the process, a little white oxyd usually sublimes, and a solid vitreous mass of arsenic acid remains at the bottom of the retort, which, when heated red hot, becomes perfectly pure.

Arsenic acid is a solid vitreous mass, of a milky white colour: its sp. gr. according to Bergman, is = 3.391. It fuses at a temperature a little below red heat, and becomes a transparent colourless fluid; but by cooling, it again becomes milky. When raised to a full red heat, it begins to boil, and gives out a portion of its oxygen; being slowly converted into white oxyd of arsenic, which sublimes in proportion as it forms. If this experiment is performed in a covered crucible, after a time, almost the whole of the arsenic acid will be dissipated, and the residue will be found closely adherent to the sides of the vessel, having dissolved a portion of its earth, and being thus converted into a permanent glazing. Arsenic acid is wholly insoluble in alcohol; but has so strong an affinity with water, as to deliquesce by exposure to a moist air: it dissolves completely in three or four times its weight of water, and has not been obtained in a crystalline form, either by refrigeration or evaporation. It has a sour, caustic, metallic taste, and reddens litmus tincture, though it produces no change on syrup of violets. Charcoal powder, digested with the aqueous solution, exerts no chemical action whatever on it, but if the mixture is distilled to dryness in a close retort, as soon as the bottom begins to grow red hot, the whole mass takes fire with violence, and the acid is deoxygenated, a beautiful sublimate of reguline arsenic being found in the neck of the retort. Sugar, and oil of turpentine, or any of the expressed oils, are charred even by digestion with a saturated solution of the acid. Six parts of the acid digested with one of sulphur suffer no change, but when the mixture is distilled in a close retort, as soon as the water is driven off, and the sulphur begins to melt, a sudden combination takes place, accompanied by a copious extrication of sulphurous acid gas, and the whole contents of the retort rise almost instantaneously, and attach themselves to the upper part in the form of beautiful realgar. It combines with various alkaline, earthy, and metallic bases, forming a genus of compound salts, known in chemistry by the name of ARSENIATS. None of the acids appear to have any action on the arsenic, for though it is soluble in some of them, it may be separated again unchanged. It unites with the boracic and phosphoric acids by fusion, but neither suffers nor occasions any decomposition.

The order of its affinities, according to Pearson, are, in the moist way, lime, barytes, strontia, magnesia, potash, soda, ammonia, alumine, metallic oxyds, water.—In the dry way, lime, barytes, strontia, magnesia, potash, soda, metallic oxyds, ammonia, alumine.

§ 10. Arseniats.

1. Arseniat of Potash.

If a solution of arsenic acid is dropped into caustic potash, till the mixture ceases to change syrup of violets green, and turns tincture of litmus red; thus shewing an excess of acid; there will be obtained by evaporation a crystallizable salt, arseniat of potash. But if on the other hand potash be added to arsenic acid till the mixture turns syrup of violets green, but produces no change on tincture of lit-

mus, an uncrystallized salt is the result, which being evaporated to dryness, again deliquesces on being exposed to the air. These varieties of arseniated potash are, however, rarely made by the direct union of their component parts, but from the white oxyd of arsenic and nitre. The phenomena attending this process we shall therefore first explain, before we enter upon an enumeration of the properties of the salt.

Let any quantity of nitre be melted in a crucible, the bottom of which is heated red, and small portions of white oxyd of arsenic be projected at intervals, taking care not to add a second portion till the effervescence and disengagement of the nitrous gas occasioned by the former has ceased. By degrees the matter in the crucible, provided the heat is not augmented, will grow thick; and being then examined by solution and crystallization, will be found to redden litmus, and consist of arseniat of potash in a crystallizable state, and some undecomposed nitre. If, however, the mass in the crucible is kept for a few minutes at a little higher heat, it will enter into perfect fusion, and give out some nitrous gas; after a short time it will again grow thick, and being then dissolved in water, will turn syrup of violets green, and refuse to crystallize, forming what Macquer and the old chemists call *Nitre fixed by arsenic*.

If a mixture of equal parts of nitre and white arsenic be put into a crucible (or still better, into a Florence flask), and the flask be heated gradually in a sandbath, till its bottom is obscurely red, there will happen a very copious disengagement of orange-coloured vapours; when these cease, the vessel is to be withdrawn from the fire, and will be found to contain a white saline mass, which by solution in hot distilled water, and evaporation, will yield arseniat of potash, formerly called after the inventor *Macquer's neutral arsenical salt*. When, on the contrary, two parts of nitre and one of white arsenic are subjected to the above treatment, the result is an uncrystallizable deliquescent mass, the alkaline arseniat of potash. This may be converted into the crystallizable or acidulous arseniat, either by the addition of arsenic acid, in which case the whole will be arseniat of potash, or by sulphuric acid, which neutralizing the alkali, the liquor will yield by crystallization arseniat and sulphat of potash. In opposition to these facts, which are mentioned by Bergman, Scheele, Macquer, and most modern chemists, Pelletier has recorded an experiment, which, though he draws no conclusions from it, seems incapable of being reconciled with the theory of an alkaline and acidulous arseniat of potash. He mixed, according to the process of Lefevre, two ounces of white arsenic with four of nitre, and put the whole into a large crucible, the mouth of which was then closed with a smaller inverted crucible pierced with a small hole to give vent to the nitrous vapour. It was subjected first to a very gentle heat for three hours, and then exposed to a red heat for eight hours longer. The matter thus prepared was a compact saline white mass, easily separating from the crucible, and weighing one gros less than four ounces. Being dissolved in distilled water and filtered, there was separated a gelatinous mass, consisting no doubt of some of the potash combined with the earth of the crucible. The clear liquor that passed the filter afforded by evaporation crystals of arseniat of potash, and the mother water consisted almost wholly of caustic potash, which united quietly with sulphuric acid, and formed sulphat of potash. Here therefore we have an example of the crystallized arseniat formed in the midst of caustic potash, a circumstance wholly unaccountable if an excess of acid is necessary for this purpose.

Arseniat of potash crystallizes in rectangular quadrilateral prisms, terminated by four-sided pyramids. In close

vessels it fuses at a low red heat, but shews no signs of decomposition; when made to boil violently in an open vessel it gives out oxygen, and acquires alkaline properties. It neither effloresces nor deliquesces in the air. It is soluble in about six parts of boiling water, and deposits crystals by cooling. It is decomposable by lime and barytes, either in solution or by fusion, the acid quitting the alkali to unite with the earths. The sulphuric, nitric, and muriatic acids, abstract from it the alkaline base, setting the arsenic acid at liberty and forming sulphat, nitrat, or muriat of potash. It decomposes and precipitates almost all metallic oxyds from their combinations, forming insoluble metallic arseniats. In the dry way, it is decomposed by charcoal, and the product is reguline arsenic of great beauty and purity, and carbonated potash. Sulphur, iron, and zinc, also decompose this salt, the reguline arsenic combining with one part of them, while the other is oxygenated.

2. *Arseniat of Soda.*

According to Scheele, if soda is saturated with arsenic acid, crystals of arseniat of soda are obtained, similar in figure to those of the preceding salt; however, the solution of them has no effect on litmus, but turns syrup of violets green. Some arsenic acid superadded, takes away the crystallizability of the mass, which, when evaporated to dryness, deliquesces in the air. Pelletier, by decomposing nitrat of soda by oxyd of arsenic, in the manner already recited for preparing arseniat of potash, obtained a permanent salt in truncated hexahedral prisms. The other properties of arseniat of soda are unknown; probably, however, they are analogous to those of the preceding article.

3. *Arseniat of Ammonia.*

Liquid ammonia, saturated with arsenic acid, affords by evaporation a salt similar in form to the rhomboidal crystals of nitrat of soda. It turns syrup of violets green, but produces no change on litmus; by a gentle heat it becomes opaque, and part of the ammonia flying off it exhibits an excess of acid. In this state it forms long acicular acid crystals, which deliquesce in the air. When distilled, it first gives out some ammoniacal gas, then fuses, and again becomes solid after it has parted with some oxyd of arsenic which sublimes. By a further increase of temperature it again becomes fluid, and is now found to be wholly changed into arsenic acid. Muriat of Ammonia is decomposed by distillation with three parts of arsenic acid. There first rises muriatic acid, then ammoniacal gas, afterwards oxyd of arsenic, and arsenic acid remains behind; hence it is obvious that part of the arsenic acid is deoxygenated at the expence of a portion of the ammonia.

4. *Arseniat of Lime.*

If arsenic acid is dropped into lime water, a white precipitate is thrown down, which is resolvable in a fresh portion of acid; the solution being now evaporated, small crystals are obtained of arseniat of lime. Another way of procuring this salt, is by digesting chalk in arsenic acid. An effervescence ensues, and afterwards by cooling, copious crystals are deposited. Arseniat of lime is sparingly soluble in water, and the solution is decomposed by sulphuric acid, sulphat of lime being precipitated. The affinity of arsenic acid for lime, is also inferior in the moist way to nitric, muriatic, or even acetic acid. Yet nitrat, muriat, and acetate of lime are decomposable by means of double affinity, by the uncrystallizable arseniat of potash, and the arseniats of soda and ammonia, arseniat of lime being in all these cases precipitated. This salt, if heated strongly in a close crucible, enters into fusion, forming a white enamel-like mass, but without undergoing any decomposition; by mixing with charcoal and subsequent heating, the greater

part of the acid is oxygenated, and reguline arsenic is sublimed. Arsenic acid in the dry way has so powerful an affinity for lime, as to be capable of uniting with this earth to the exclusion of sulphuric, fluoric, and nitric acids.

5. *Arseniat of Magnesia.*

Acid of arsenic, when digested upon magnesia to saturation, forms a coagulum; this being dissolved in a fresh quantity of arsenic acid, and evaporated, yields a jelly which by further privation of its moisture is converted into an uncrystallizable viscous mass. The sulphat, nitrat, muriat, and acetate of magnesia, are not decomposable by arsenic acid, but readily so by the alkaline arseniats; the precipitate thus produced is insoluble in water, but readily so by acids. When heated in a close vessel with charcoal, it exhibits the same phenomena as arseniat of lime.

6. *Arseniat of Barytes.*

This salt may be obtained in an earthy form, according to Scheele, by digesting the acid upon barytes; at first the barytes dissolves readily, but when the acid is saturated, a spontaneous precipitation of arseniat of barytes takes place. Fourcroy informs us, that it may be procured in a crystalline form by mixing a warm concentrated solution of acetate of barytes and arseniat of potash; a decomposition takes place, and bright spicular needles of arseniat of barytes are deposited. In the moist way this salt seems undecomposable except by sulphuric acid and the easily soluble sulphats. In a full red heat, however, even sulphat of barytes is decomposed by arsenic acid, the sulphuric acid being volatilized.

7. *Arseniat of Alumine.*

Moist earth of alum is readily soluble in arsenic acid, and by evaporation it yields a gummy uncrystallizable mass. The alkaline arseniats will occasion a precipitate in sulphuric, nitric, and muriatic acids, previously saturated with earth of alum, and this precipitate is soluble in acids, though not so in water. It must however be remembered, that the earth precipitated from ALUM by an alkali is not pure ALUMINE, and therefore that the preparation here described is not arseniat of alumine. Scheele indeed expressly mentions, that the solution mixed with charcoal, and evaporated to dryness, and then ignited in a close vessel, yields a sublimate of orpiment, together with reguline arsenic and sulphureous acid, and that the residue, when dissolved in sulphuric acid, deposits after a time some crystals of alum. The arsenic acid, even by a long digestion with white clay, does not take up any portion of it. One part of clay and four parts of acid combine by fusion into a vitreous mass; and this, by being again heated with charcoal, affords a beautiful sublimed regulus of arsenic.

The combinations of stontia, and the other earths with the arsenic acid, have not as yet been examined. The metallic arseniats will be found under the several metals.

§ 11. *Historical Notice concerning Arsenic.*

The native sulphuret of arsenic, was the only one of the arsenical ores known to the ancients. Aristotle speaks of the *Σανδαράχη*; and his pupil Theophrastus, in his treatise on minerals, mentions the *Αρσενικός*, corrupted afterwards by Dioscorides and others into *Αρσενικός*. Pliny also, in his Natural History, describes the arsenicum, auripigmentum, and sandaracha. The Syrian orpiment, probably from its colour, was supposed to contain gold, and an ineffectual attempt by order of the emperor Claudius to extract this metal from it, is recorded by the Roman naturalist just mentioned. The sandaracha of Pliny is realgar, being represented by him as friable, of a ruddy colour, and analogous to litharge. His arsenicum is expressly said to be of the same substance as sandaracha, and is thus described.

"The colour of the best is superior even to gold; the inferior sorts are paler, or else approach to the hue of sandaracha. It is of a scaly texture." The two last do not appear to have been considered of the same nature as auripigmentum: and the only use to which they were applied, was that of a caustic in medicine, and a pigment. The first mention of white arsenic is in the works of Avicenna, who lived in the 11th century. Paracelsus affirms, that arsenic sublimed with egg-shells becomes like silver; and in 1673, Lemery published the method of obtaining the regulus by sublimation from a mixture of white arsenic, fixed alkali, and soap. Albertus Magnus and Beccher considered arsenic (by which they meant the white oxyd) as of a saline nature. Kunkel was also of the same opinion; and Macquer, by his discovery of the arsenite and arseniat of potash, demonstrated that in these combinations it held the place of an acid. Finally, Scheele proved, that the base of arsenic (according to the Stahlian theory then in vogue) was not only similar to, but was actually an acid, by discovering the method of obtaining it in an uncombined state.

Arsenic being found in the ores of many metals, often serving as a mineralizer to them, and adhering with great obstinacy to them even when brought into the state of regulus, was long considered, like mercury, as an essential component part of metallic substances, nor was this opinion abandoned till the celebrated essay of Monnet in reply to a prize question proposed by the Royal Berlin Academy, in 1773, on the nature and peculiar agency of arsenic in the formation of metals. In this treatise he shews arsenic to be a peculiar metal, essentially differing from all others, and instead of being a necessary component part of them, is often totally absent, and when present is so far from perfecting them, that it always deteriorates and obscures their characteristic properties.

§ 12. *Uses of Arsenic.*

In the reguline state, it is used to whiten COPPER, and enters as an ingredient in several kinds of SPECULUM METAL. Oxyd of arsenic is employed as a poison for rats and other vermin, and a flux in GLASS-making. Orpiment and realgar are of extensive use in DYING and CALICO-PRINTING, and as a pigment. For the deleterious properties of arsenic, and its medical uses, see the next article.

Plinii Hist. Nat. Bergman's Essays. Scheele's Essays. Pelletier, Memoires de Chimie, vol. i. Encycloped. Method. art. Arsenique. Fourcroy, Syst. des Connoiss. Chem. vol. v. Macquer's Chimisches wörterbuch, art. Arsenik. Gren's Systematisches handbuch der Chemie, vol. iii.

ARSENIC, in Pharmacy, and its Operation upon the Human Body.—Arsenic is perhaps of all natural substances, that which exerts the most virulent and dreadfully active operation upon the living animal, when taken into the stomach or any other part of the system.

We are, unfortunately, too familiar with its effects as a poison; its cheapness and abundance rendering it easily accessible to malevolence, or obnoxious to carelessness, and the history of almost every year adds to the number of sufferers from this formidable mineral.

Nevertheless, as every poison, when judiciously managed, may be converted into a powerful medicine, several very skillful practitioners have attempted, and not without advantage, to add this substance to the materia medica, and hence the effects of arsenic become important to the physiologist in a double point of view, both that he may relieve and counteract them, when they operate as a poison; and manage them with judgment and caution, when they are intended to cure disease.

We may begin by observing, that all the preparations of arsenic appear, as far as experience goes, to operate in a similar manner, though some with much more activity than others, in proportion to their quantity; and likewise it is fully ascertained, that sulphur moderates the operation of this metal in a very striking manner, as indeed it does that of all the other metallic medicines. This comparative mildness of the sulphuret may be the reason why the native orpiment and realgar have been employed medicinally for ages by some of the oriental nations, particularly, among other cases, as an antidote to the bite of the cobra, and other venomous serpents; and we may remark, that the native arsenical sulphures (as observed by Hoffman, and confirmed by subsequent experiments) are much milder and safer in their operations, than any of the artificial combinations of these two minerals.

When the active arsenical salts (the white arsenic for example) have been taken into the stomach in the quantity of a few grains or upwards, the most dreadful consequences are observed to succeed: these are, first, a most horrible and almost indescribable anxiety at the pit of the stomach, to which succeeds a very acute burning pain in this organ, generally attended with violent retching and vomiting, whereby, indeed, the life of the sufferer is sometimes preserved, owing to the rejection of the arsenic; this is often followed with severe purging, and the pain proceeds with increased virulence, to the bowels and almost the whole of the alimentary canal; to this succeed in a shorter or longer time convulsive tremors of the limbs, cold sweats, and a very sudden and characteristic swelling of the emphysematous kind, which puffs up the face, the neck, and at last every other part of the body. If no relief be obtained from these dreadful symptoms, they quickly proceed to the destruction of life; the unhappy sufferer becomes insensible to surrounding objects, lying on his belly, with every muscle distorted by the violence of the pain, his hands clenched, his eyes bloodshot and glassy, his jaws now immovably fixed, and unable to swallow either solids or liquids, his limbs convulsed with severe cramps, his face and neck so much swelled that the features can hardly be recognized, till at last death terminates his agony. On inspecting the body after death, the stomach is always found highly inflamed, partly gangrenous, and often actually corroded by sphacelated spots. The same inflammation and partial mortification also extends in most cases to parts of the small intestines. The body is said to putrefy with remarkable rapidity.

Even when persons have recovered from poisoning by arsenic, they feel its effects long after in griping pains, tremors of the limbs, partial paralysis, loss of appetite, and often a lingering hectic fever, which remain for a considerable time, and without great attention to health, are apt materially to injure the constitution. An exposure to the fumes of arsenic occasions similar accidents, particularly griping, bloody urine, and contraction of the body, and sometimes a general eruption like the nettle-rash; and hence in all chemical operations with this dangerous metal, the operator should be particularly cautious of avoiding its noxious fumes.

Arsenic when applied to any wounded or ulcerated surface of the body, is equally liable to produce the above-mentioned symptoms in a greater or lesser degree; but as the first that appear are generally pains in the stomach and bowels, and swelling of the face, sufficient warning is hereby given to withdraw the cause of them.

A variety of remedies against the poison of arsenic has been proposed, all of which are intended to fulfil these two indications, to remove the noxious ingredient, and to protect the alimentary canal from its baneful operation. The first object is to get rid of the poison by most copious vomiting

and purging; and for this purpose all the substances known to produce these effects, may be employed with the greatest freedom. It has been thought that the rougher mineral emetic and purgative medicines should be avoided, and certainly the milder vegetable substances appear the most eligible; but it is of such infinite consequence to apply an *immediate* remedy, that the preference due to one over another medicine can hardly ever be equivalent to the mischief incurred by allowing this most corrosive and deleterious of all poisons to remain a moment longer in the stomach than can be avoided. Hence the first emetic medicine at hand is always the best, nor should the mechanical means of exciting vomiting, as by thrusting a feather down the throat and the like, be neglected. In the intervals of vomiting, the stomach should be deluged with any mild mucilaginous liquid that is at hand; milk, gruel, linseed tea, broth, oil of any kind, or even warm-water, in the largest possible quantity, should be taken, and where the arsenic itself excites constant vomiting, as is often the case, no other remedy than these mucilaginous or oily liquids is required. These should be assiduously persevered in till the burning pain and other symptoms produced by the arsenic are removed, and only the soreness consequent to such a violent exercise of the alimentary canal remains; after which a cautious and judicious use of opiates will prove of material benefit: but the state of health will require much attention for a considerable time, before the constitution can entirely recover the effects of so rude a shock. When the poison has remained so long in the stomach that the sufferer lies insensible, racked with pain and unable to swallow, recovery seems to be hopeless; in such cases, the most probable method of exciting vomiting is to lay some tartar emetic upon the tongue, part of which may perhaps be carried by the saliva into the stomach, and relieve it from the poisonous mineral.

Some ingenious men have endeavoured to discover an antidote to arsenic, in the proper meaning of the term; that is, a substance which may prove a peculiar corrective to its baneful effects, by uniting with it when in the stomach, and destroying its acrimony. The well-known effect of sulphur to mitigate the operation of all metallic bodies, readily suggested this as the desired remedy, and the liquid alkaline sulphuret was proposed by Navier, an eminent physician of Chalons in France. Fourcroy has suggested the liquid hydro-sulphures (or solutions of sulphurated hydrogen in water, of which the sulphurated mineral waters are familiar examples) as an improvement on Navier's remedy. Experience, however, has not confirmed the utility of either of these preparations. It is true, that if the poison and the antidote were previously mixed, and in a state of solution, the former would be disarmed of its terrible powers; but to trust to the chance of a mere chemical operation in an organ so irritable as the stomach, so dreadfully susceptible of active inflammation, and actually suffering under a violent injury which is hastening the destruction of the whole system, is to carry the ideas of a laboratory much beyond the bounds of sober prudence and sound practice.

It has been urged, however, that after the immediate danger from arsenic has been removed by the liberal use of emetics and emollient liquids, much advantage may be derived from the use of the liquid sulphurets. But at this period we have not (in all probability) any of the arsenic to remove, but only the inflammation, the effects of arsenic, and on what ground can sulphurated hydrogen be supposed to be of use in inflammation of the stomach and bowels?

The medical chemist is sometimes called upon by the magistrate to ascertain the presence or absence of arsenic in the stomach of persons who have died with some of the vio-

lent symptoms above described. Some of the appearances, on dissection, have been already mentioned. The presence of arsenic, in substance, in the stomach, is thus ascertained: first, make a ligature round the lower part of the œsophagus, and another at the pylorus, to prevent any of the contents of the stomach from spilling; then take out this organ, empty its contents in a basin, and rinse the inner surface with a little cold water, which add to the other contents. As white arsenic, in substance, is generally that which is found after death by this poison, it will be seen in the form of a heavy white powder, from which the slime, and other contents of the stomach, may be washed off by repeated affusions of cold water, which washings, however, should not be thrown away, but added to the liquid contents. Then let the powder be submitted to the following experiments: boil a portion of it in a Florence flask, in a few ounces of distilled water, and filter the liquid solution; add to a part of the clear liquid some water saturated with sulphurated hydrogen gas, or a few drops of sulphuret of ammonia, and if arsenic be present, a golden yellow sediment will fall down, which will appear sooner if a few drops of acetic acid be added; add to another portion of the solution a single drop of a weak solution of carbonate of potash, and afterwards a solution of sulphate of copper, when the arsenic will be indicated by a yellowish green precipitate, similar to that which is known in chemistry by the name of *Scheele's green*; collect the sediments and dry them, or if there is any of the powder to spare, take a portion of this, lay it upon red hot charcoal, when it will be entirely dissipated in a white dense vapour, having the garlic smell peculiar to arsenic.

But a portion of the white powder suspected to be arsenic should be reduced to the metallic state, which may be done in the following neat manner, proposed by Dr. Black: mix it with two parts of dry carbonate of potash, and one of powdered charcoal; procure a tube eight or nine inches long, and one-sixth of an inch in diameter, of thin glass sealed hermetically at one end; coat the closed end with clay for about an inch, and let the coating dry; then put into the tube the mixture of the powder and the flux, and if any of it should adhere to the inner surface, let it be brushed down by a feather; stop the open end of the tube loosely with a cork, and gradually heat the sealed end only, on a chafing-dish of hot charcoal. The arsenic, if present, will then rise to the upper part of the tube, on the inner surface of which it will form a thin, brilliant, metallic coating, whilst a portion will escape in garlic smelling fumes. When nothing more rises from the heated end, break the tube, and scrape off the metallic crust formed on the upper part. Of this, lay a part on heated iron, when it will totally exhale in a dense smoke, with the peculiar arsenical smell; put another part between two polished pieces of copper (halfpence, for example, rubbed quite bright), bind them together with wire, and expose them slowly to a low red heat; if the enclosed substance is arsenic, it will leave a white stain on the copper.

If it should happen that no white powder is found in the stomach, the liquid contents, when filtered along with the washings, should be evaporated to dryness, and the residue examined in the same manner as the white powder; but this would be a work of greater difficulty on account of the casual mixture with the other contents of the stomach.

By these means the presence of arsenic, even in very small quantity, may be detected by any one tolerably versed in chemical experiments; but, for greater security, it may be advisable to perform separate and parallel experiments with the white arsenic of the shops, and compare the results and appearances.

It is a matter of common observation, that no vegetable or mineral poison, however virulent, exists, which in diminished quantity and by prudent precautions may not be converted into a valuable remedy. This observation will apply even to arsenic, and we have the most respectable testimony to its value in the cure or relief of some complaints which entitles it to considerable notice. The medicinal use of the sulphurets of arsenic may be traced back to very early times, and the Greeks and Romans appear to have used it with considerable freedom. Dioscorides observes that the arsenic (*arsenicum*) is found in the same minerals which produce the sandarach. The best for medicinal purposes, he adds, is of a golden colour, unmixed with any other substance, which easily separates into scales, and comes from Mysia on the Hellespont. An inferior sort comes from Pontus and Capadocia. It is prepared by roasting on hot coals, with constant stirring till it takes fire, and alters in colour, when it is to be cooled and carefully pulverized. The sandarach is prepared in the same manner as the arsenic or orpiment, and possesses the same virtues. When taken internally, they have a violent corrosive and astringent operation, exciting a burning on the skin, and causing the hair to fall off. These arsenical powders were used principally as external applications, mixed with pitch, oil, or fat, against a variety of cutaneous complaints, itch, phthiriasis, and other defecations of the skin, and also to ulcers of the nostrils and mouth, and condylomata.

Much attention has been bestowed in modern times to the power laid to be possessed by arsenic of relieving or curing cancers, when employed both as a topical application, and taken into the stomach. The progress of this disorder is so dreadful, and the remedies usually employed have proved so inadequate to stop its ravages, that any medicine, however severe, may be employed without censure, which affords a chance of permanent relief. We have still to regret that the flattering hopes of a cure, and the real benefit often produced by this metal, have not been confirmed by frequent experiment; but the virtues of this remedy, however, are too important to be neglected. Several medical practitioners and empirics have gained much credit for supposed cures of cancers by remedies which appear to have been arsenical; and Mr. Justamond, in his valuable *Surgical Treatise* (London, 1789), gives the recipe of an arsenic caustic, called "the earl of Arundel's receipt to cure a cancer," and found in the Harleian MSS. which appears to have been divulged by a woman in the lower order of people, in the year 1638, whose father had long employed it for the cure of cancers.

Mr. Justamond, in his ingenious work above quoted, gives the history of many cases of cancer in different stages, in which the following arsenical preparations were topically applied:

1. The earl of Arundel's receipt above mentioned, composed of one ounce of yellow arsenic, and half an ounce of bole armenic; or else of one ounce of the yellow arsenic, half an ounce of the red precipitate, and half an ounce of bole armenic.

2. A sulphuret of arsenic, formed in the following way: Take four pounds of sulphur, and one pound of white arsenic, mix and put them into a glass retort, on a sand heat, and lute to the retort a long neck and receiver: raise the fire gradually till the mixture be fused: reject the sublimed portion, and reserve the fixed matter beneath, which must be finely levigated.

3. A mixed sulphuret of arsenic and antimony, formed by melting together in a crucible, with a very moderate heat, the native black sulphuret of antimony (or the common an-

timony of the shops), with white arsenic, in proportions varying according to the intention; being two parts of arsenic to one of antimony, where a violent arsenical caustic is wanted; and two parts of antimony with one of arsenic, where a milder escharotic is required.

Mr. Justamond began the above arsenical application, to the open or ulcerated cancers, which he used in the form of powder or scrapings, laid to the most ulcerated parts, whilst he frequently moistened the hard retracted edges of the wound with a solution of muriated iron, with sal ammoniac.

The immediate effect of the arsenic was to give a most acute and burning pain, which constantly attended every fresh application, and probably would be hardly tolerable to any, but to those who are suffering under one of the most dreadful, harassing, and hopeless disorders which ever come under the care of the surgeon. The first beneficial effect of the arsenical powder, was to correct, and almost entirely to remove the thickening flench which attends these species of ulceration; and this was invariably the case, even when it failed to give any other relief. Afterwards the powder (where successful) evidently improved the condition of the sore, and by repeating it daily, with much perseverance and attention, Mr. J. happily succeeded in producing a complete cure. It was only, however, in one or two instances that this was effected; and in others, the poison of the arsenic absorbed into the system, produced its baneful operation with so much rapidity, bringing on partial palsy, and severe pain with cramp in the bowels, that he was obliged instantly to discontinue it; with the unpleasant feeling, that he had added to the already diseased constitution of his patient, the severe disorder occasioned by the arsenical remedy itself. Mr. Justamond then made a trial of the stronger arsenical caustic (two parts of arsenic fused with one of antimony), to scirrhous tumours of the breast, before they had proceeded to ulceration, with the view of turning them out entire, or as it were dissecting them out by caustic, instead of the knife. In this he followed the example of Guy and Plunkett, who had been celebrated for this species of operation, an operation only to be undertaken when the patient is too timorous to submit to the safer and more expeditious use of the knife. Mr. J. mixed the arsenical caustic with an equal weight of opium, brought the powder to the consistence of an ointment by the yolk of an egg, and having the day before separated the cuticle of the tumour by lunar caustic, he applied the arsenic over the whole surface. The pain was very great for twenty hours, after which it subsided. After some days the tumour began to separate, and by repeating the caustic round the separating edges, the scirrhous gland, in about two months, "came out entire as a nut out of its shell, or as if it had been cleanly dissected with a knife."

We shall proceed to enumerate some of the other noted arsenical preparations, employed externally to cancers and scirrhous tumours. The following is given as Plunkett's celebrated arsenical caustic, with which the inventor used to extirpate scirrhous tumours before they had arrived to ulceration.

4. Take of the leaves of the *ranunculus acris* (crowfoot), and of the *flammula vulgaris* (lesser crowfoot, also a species of *ranunculus*), of each one ounce; of white arsenic levigated, one drachm; of flowers of sulphur, five scruples. The two former plants being fresh gathered and bruised, the arsenic and sulphur are to be added, and the whole beaten into a paste, which is to be formed into balls, and dried in the sun. When used they are to be beaten up with yolk of egg, and applied on a piece of pig's bladder to the surface

of the tumour. This is to remain till the escharotic separates spontaneously. The *ranunculus*, which is an acrid plant, is not here an useless addition, as it assists in separating the cuticle, and till this is done the arsenic is scarcely able to act.

5. The *arsenicum citrinum* (*galber arsenik*) employed at Vienna, is one of the strongest of these preparations, being composed of ten parts of arsenic sublimed with one of sulphur. When used, the scrapings of it are laid on the cancerous ulcer till it is consumed. The pain which it occasions is most severe.

Mr. Febure's arsenical remedy (*Remède éprouvé pour guérir radicalement le Cancer occulte ou ulcéré*, Paris, 1775), which excited much attention at the time, is the following:

6. Take one pint of water; one ounce of extract of cicuta; three ounces of Goulard's extract; one drachm of liquid laudanum; and ten grains of arsenic; mix them into a liquid, with which the cancer is to be smeared every morning and evening.

Lastly, of the external applications, we may mention the following, which is simple, and probably as efficacious in ulcerated cancer as any of the preceding.

7. Take a solution of white arsenic in water, in the proportion of one grain to two pints, mix it with crumb of bread into a poultice, and apply it to the open sore.

Febure appears to be the first who ventured to recommend the internal use of arsenic in the cure of cancer; a practice which has rarely been openly followed, though probably this mineral forms the basis of many of the empirical remedies for this disease. Febure's internal arsenical medicine is the following:

8. Take of white arsenic, two grains; of syrup of chicory with rhubarb, half an ounce; of water, one pint. Of this one table spoonful is given every morning and evening, in an ounce of milk, with half a drachm of syrup of poppies. The dose is to be gradually increased as the patient can bear it.

Mr. Justamond also was able to give internally as much as five grains of the arsenical sulphuret ($N^{\circ} 2$.) daily, without injuring the patient.

The inference which the reader will be disposed to draw from all that we have given, concerning the efficacy of arsenic in cancerous complaints, will not probably be very encouraging to its use. The actual pain attending its application is always very acute, though perhaps not more so than the disease itself; but the quantity of the remedy here requisite, either for external or internal use, is so considerable, as to incur great danger of poisoning the constitution irretrievably, and inducing calamities almost equal to those which it is designed to counteract.

With more satisfaction we can conclude our account of this mineral, with a history of its employment in another obstinate and often dangerous disorder, in which it promises very great advantage, unattended with any considerable risk where managed with great prudence and discretion. This is, in obstinate and lingering agues, such as have resisted ordinary remedies, and are proceeding gradually to undermine the constitution by their periodical and repeated paroxysms.

We owe the introduction, or at least the publicity of this remedy to Dr. Fowler's highly valuable series of experimental cases, undertaken in the Stafford infirmary, in 1784, and published in the following year. The circumstance that directed his attention to this remedy, was the very great sale and successful operation of certain *patent ague drops*, which were (probably with reason) supposed to be a preparation of arsenic.

Dr. Fowler's arsenical solution is thus prepared.

9. Take white arsenic in fine powder, and pure salt of tartar, of each sixty-four grains, put them into a Florence flask, or other glass vessel, along with half a pint of distilled water, heat them slowly to boiling, till the ingredients are dissolved; when cold, add half an ounce of compound spirit of lavender, and distilled water sufficient to make up the whole quantity one pint, or rather fifteen ounces and a half troy-weight.

Of this solution, one ounce, apothecaries measure, contains four grains of arsenic, or one dram, half a grain; and Dr. F. calculates each dram to be equivalent to eighty drops.

In preparing this liquid, the operator should be aware that the salt of tartar of the shops, even the purest, seldom makes a perfectly clear solution with water, but leaves a small earthy sediment, which no continuation of the boiling will dissolve. Instead of this alkali, twice the weight of pure nitre has been employed, which promotes the solubility of the arsenic, and is perhaps somewhat preferable to the salt of tartar. These salts are not necessary to the immediate solution of arsenic, but they prevent this metallic oxyd from separating again from the water by long keeping.

The proportion of arsenic to water, in the solution, may be varied from the form above given; but as white arsenic requires eighty times its weight of cold water to remain dissolved, not less than this quantity should be employed, and the nitre or alkali should never be omitted, as it is of the utmost importance for the practitioner to know precisely the dose of arsenic which he prescribes.

Dr. F. found that for the cure of intermittents it was of importance to give the arsenic in divided doses as fast as the patients could bear it, without experiencing inconvenience from its poisonous effects. Strong adults could generally bear about ten drops of the solution (equivalent to one-sixteenth of a grain of arsenic) for a dose, which he repeated twice, or, if convenient, thrice a day. By slow increase, some were able to bear as much as twenty drops for a dose, and this course was continued for five days, when, if the fits of the intermittent were suspended, the drops were interrupted for two or three days, and then resumed for three days longer to prevent a relapse.

Infants could bear about two drops twice a day, and young or delicate persons took the solution in intermediate doses from two to ten or twelve drops.

The operation of this powerful remedy was truly surprising in checking almost immediately, and finally removing the paroxysms of the most obstinate intermittents, some of which had resisted bark and other remedies for a considerable time. In a few, however, it failed entirely; and in others the poisonous effects of the arsenic came on so speedily that it could not be continued, and the cure was completed by bark and other tonics.

Every practitioner will be aware of the great caution necessary in the exhibition of a remedy, which, though safe in prudent hands, might induce the most dangerous accidents if exposed to carelessness or ignorance. In most of the successful cases, the medicine removed the disease without producing any of the inconveniences attending its use in larger doses; but when the arsenic began to shew its poisonous effects, the symptoms were, nausea, often accompanied with a slight griping and purging, swellings of the soft integuments of the body, particularly the face, sometimes uneasiness at the stomach, and a slight eruption like the nettle-rash; and, in a very few instances, head-ach, sweat, and slight tremors. By attending to these serious and very characteristic warnings, and by the assistance of gentle aperients, opiates, and other means which will readily suggest themselves to the prudent physician, this terrible mineral may be enlisted into the service of the healing art, whilst its cheapness, insipidity, and great activity in a very small bulk, may sometimes render it preferable to the safer drugs and barks, which oppress the stomach by their bulkiness, and disgust by their nauseous flavour.

We may add that,

10. The arseniat of potash, described in § 10. of the preceding article, has been employed in intermittents with the same effect as the solution, and its ready solubility and uniformity of composition may perhaps give it a claim to preference. The medium dose of this salt may be a fifth of a grain three times a day.

Arsenic has been occasionally employed with considerable success, when applied to the surface of the body in a variety of cutaneous complaints; and it might be adopted with more freedom, if it were not for the extreme danger to which any neglect of the warning symptoms of poisoning might expose the patient, a danger the more likely to be in chronic complaints often neglected, and not always sufficiently under medical inspection. Orpiment mixed with tar, with digestive ointment, or other unctuous substances, has been found of eminent service in tinea capitis, a prescription handed down to us from the ancients; but if the medical practitioner will venture on this hazardous, and not often necessary remedy, he should never forget the much superior virulence and activity which the artificial orpiments and arsenical sulphurets possess over the natural. Orpiment and quicklime, boiled in water for a short time, form a liquor which, if often applied to the cuticle, causes the hair to fall off; and the growth of it, when thus checked, is seldom renewed. Dioscorides. Plenck's *Pharmacologia Chirurg.* 1782. Fowler's *Medical Reports on the Effects of Arsenic*, 1786. Justamond's *Surgical Tracts*, 1789. *Pharm. Danica*. Henry's *Epitome of Chem.* 1801, &c.

Battery

BATTERY, in *Electricity*, is a combination of coated surfaces of glass, so connected together, that they may be charged at once, and discharged by a common conductor. Mr. Gralath, a German electrician, was the first who contrived to increase the shock, by charging several phials at the same time. Dr. Franklin, after he had analyzed the Leyden phial, and found that it lost at one surface the electric fire which it received at the other, constructed a battery, consisting of eleven panes of large sash-glass, coated on each side, and connected in such a manner that the whole might be charged together, and with the same labour as one single pane; and by bringing all the giving sides into contact with one wire, and all the receiving sides with another, he contrived to unite the force of all the plates, and to discharge them at once. A more complete battery is described by Dr. Priestley, of which he says, that after long use he sees no reason for wishing the least alteration in any part of it. This battery (see *Plate I. Electricity*, *fig. 1.*) consists of 64 jars, each ten inches long, and $2\frac{1}{2}$ inches in diameter, coated within $1\frac{1}{2}$ inch of the top; and contains in the whole 32 square feet. The wire of each jar has a piece of very small wire twisted about the lower end of it, to touch the inside coating in several places; and it is put through a pretty large piece of cork, within the jar, to prevent any part of it from touching the side, which would tend to promote a spontaneous discharge. Each wire is turned round, so as to make a hole at the upper end; and through these holes a pretty thick brass rod with knobs passes, one rod serving for one row of the jars. The communication between these rods is made by laying over them all a thick chain. When part only of the battery is used, the chain is laid over as many rods as will furnish the required number of rows of jars. The bottom of the box, in which the jars stand, is covered with a plate of tin, and a bent wire touching the plate passes through the box, and appears on the outside. To this wire any conductor designed to communicate with the outside of the battery is fastened, as the small wire in the figure, and the discharge is made by bringing the brass knob to any of the knobs of the battery. When a very great force is required, the quantity of coated surface may be increased, or two or more batteries may be used. Franklin's *Exp. and Obs.* ed. 1769. p. 28. Priestley's *Hist. &c. of Electricity*, ed. 1775. vol. ii. p. 99.

However complete the battery above described appeared to be at the time of its construction, later electricians have discovered many imperfections to which it was subject; of which the principal are those that result from the form and size of the jars, the substance of the glass, the height of the coating, and the connections within the battery. In consequence of these imperfections in its structure and contrivance, it is prevented from receiving more than about half the charge which it ought to receive in proportion to the quantity of its coated surface.

The most perfect batteries of modern construction, since that of Dr. Priestley, have been made in Holland for Teyler's museum at Haerlem, by Mr. Cuthbertson of Poland-street, London, then residing at Amsterdam. Of these batteries there are two, differing in their magnitude and mode

of construction, but allowed to be equally perfect. The first was completed in the year 1784, and is composed of 155 jars in 9 boxes, each containing 15, which may be used separately or combined, as the nature of the experiment requires. Each box is a separate battery of itself; and the description of one box with a view of the figure, will be sufficient for explaining its construction and use. In *Plate I. Electricity*, *fig. 2.* is exhibited a perspective view of Teyler's first battery, with its parts arranged in proper order for receiving a charge from the electrical machine. Each box, as we have already observed, contains 15 jars; each jar is 11 inches high, and 6 inches in diameter, contracted at the mouth to 4 inches, and coated so as to contain about 140 square inches; and thus the whole battery will contain about 132 square feet of coated surface. Each box is divided into 15 partitions, 5 of which are in the length and 3 in the breadth; the height of the sides of the box being somewhat lower than the coating of the jars, as are also the partitions in which they stand. The lid of the box is made without hinges, for the convenience of releasing it from the box, that it may be removed while experiments are performed. It is taken off by lifting it upwards. The outside coatings of the jars are connected by means of cross wires passing under the bottom of each jar; and those on the inside by means of a brass frame, bearing 15 brass balls, fixed upon the frame above the centre of each jar. All these balls, excepting the four at the corners, have wires screwed to them and hanging downwards into the inside of each jar; but the wires of the four corner jars are screwed to a foot, which is cemented to the bottom of each in the inside. Upon these wires the whole frame rests, and is kept in its proper position. The four corner balls have holes, which receive the ends of the wires, and terminate at a proper height from the jars. By this contrivance the inside connecting frame may at any time be easily removed; and as this part of the machine is important, the construction of the said frame is shown separated from the battery in *fig. 3.* It is according to the above construction that Mr. Cuthbertson forms his present batteries, excepting that he has increased the size of the jars, so as to make one battery contain about 17 square feet; and he engages to prove by experiment, that the batteries of his construction are far superior to any others. Teyler's second grand battery was finished by Mr. Cuthbertson in 1789. This is the largest and most complete battery that was ever made. The whole battery, standing in proper order for receiving a charge, is exhibited in *fig. 4.* It consists of 100 jars of the same shape with that of those already described, only that they are so enlarged in size, that each of them contains $5\frac{1}{2}$ square feet of coated surface, instead of 140 inches, and the whole battery contains 550 square feet of coating; and for convenience, it is put into four separate cases, each containing 25 jars in the form of a square, 5 on each side. The boxes are lined with lead on the inside for forming the outside communication; each jar has a perpendicular stand resting upon its bottom, and supported from falling sideways by three stays on the inside. Upon the top is screwed a three inch brass globe, from which proceeds a brass tube about one inch in

diameter, to a large brass globe, supported by the middle jar at a proper height, so as to keep the inside communication properly arranged. A view of the figure will shew how the four are combined, so as to charge and discharge all the 100 jars at once.

Lieutenant colonel Haldane proposes the following method for measuring the force of an electrical battery, during the time of its being charged.

Let the battery be insulated, and at a small distance from it place an uninsulated electrical jar, and near the jar, one of Mr. Cathbertson's electrometers. The electrometer being adjusted according to the degree of force which is intended to be employed as a measure of force to be communicated to the battery, connect the electrometer with the jar; make a metallic communication between the interior side of the jar and the exterior side of the battery, and connect the interior side of the battery with the conductor of an electrical machine: then, by the operation of the electrical machine, the battery receives a quantity of the electrical fluid, and becomes charged. The fluid, which departs from the exterior side of the battery, is received by the electrical jar, which also becomes charged; but this jar, being connected with the electrometer, explodes as soon as it acquires a force sufficient to put the electrometer into motion. The quantity of the electrical fluid which is received by this jar, between each of the explosions, is a measure of the quantity of the fluid in the battery; and the number of explosions or discharges of this jar shews the number of measures which the battery contains, and consequently the force which it is capable of exerting when discharged.

For the author's demonstration of this method, and the illustration of it by appropriate experiments, we must refer to Nicholson's Journal, vol. i. p. 156, &c.

BATTERY, Galvanic; the name usually given to an apparatus for accumulating the electricity which is produced by the mutual agencies of certain metallic and carbonaceous substances, and peculiar fluids.

The first instrument of this kind was invented by the celebrated Volta of Pavia, in 1800, and various forms of it have been since adopted by different philosophers.

The original battery, or the electrical pile, is composed of plates of zinc, plates of silver, and pieces of pasteboard, of the size of the plates, moistened in a solution of salt in water: and arranged in the order of zinc, silver, pasteboard, zinc, silver, pasteboard, and so on, till a series sufficiently numerous is formed. On account of the expence of silver, copper has been lately generally substituted for it, with but little diminution of effect; and solutions of muriate of ammoniac, of nitrous acid, and of muriatic acid, have been employed instead of the solution of common salt, with very great advantage as to the increase of the power of the combination. In general any two metallic substances which are perfect conductors of electricity, may be used, provided the interposed fluid is capable of oxidating at least one of them.

The powers of galvanic batteries appear to be very much connected with the chemical changes going on in them, and hence plates of one metal may be made to supply the place of the two metals provided their different sides be exposed to different chemically acting fluids, as has been shewn by the experiments of Mr. Davy. Thus copper, silver, and lead, all form efficient combinations when they are arranged with two different sets of pasteboard, one moistened with diluted nitric acid, and the other with solution of hydrosulphuret of potash; the order being metal, pasteboard moistened with acid, pasteboard moistened with hydrosulphuret, &c. In such a case, if the battery is required to be of considerable permanency as to its effects, it is necessary to separate the

pasteboard moistened in the chemical agents from each other by a third set of pasteboards, moistened in common water.

In instances when piles are erected perpendicularly either with two metals or with one metal, in consequence of the oxidation and the loss of moisture from pressure and evaporation, the electrical action usually ceases after a few days; and in order to renew it, a second construction of the series becomes necessary. Several methods have been proposed for making instruments more permanent in their operation than the pile, and more easily rendered active; but the most ingenious contrivance appears to be that of the trough, discovered by Mr. Cruickshank. It consists of a box of baked wood, in which plates of copper and zinc, or of silver and zinc folded together at their edges, are cemented in such a manner as to leave a number of water-tight cells, corresponding to the number of the series: the arrangement becomes active when the cells are filled with the proper saline fluids; and it may at any time be easily freed from oxide by the use of muriatic acid.

In the common apparatus of Volta, that part bounded by the most oxidable metal, as, for instance, the zinc, is found in a positive state, with regard to electricity, and the other part, as the copper, in a negative state; and when a communication is made between the two ends, by means of a conducting body, a constant circulation of electricity is established.

The electricity of the galvanic battery is capable of being partly transferred into the Leyden phial, and its effects, as has been fully shewn by the experiments of Messrs. Nicholson, Carlisle, Woolaston, Van Marum, and Ritter, are similar to those of common electricity, in a low state of intensity. It gives shocks to living animal organs, and excites muscular contractions in bodies for a considerable time after death. It assumes the form of fire in passing from one conducting body to another in its highly concentrated state; and it ignites small metallic wires or leaves, and causes them to enter into combustion. It sets fire to charcoal, sulphur, alcohol, and other inflammable bodies; and it rapidly decomposes water and various other fluids.

The intensity of the electricity in Galvanic batteries is greater in proportion as the series composing them are more numerous: but the quantity of it depends upon the quantity of surface they contain. Hence equal numbers of large and small plates arranged in different batteries produce nearly the same effects on the human body which is an imperfect conductor, and which can admit of the passage only of a certain quantity of electricity of a low intensity in a given time; but the large plates are in a determinate ratio, much more powerful in igniting the metals, and in affecting perfect conductors through which a large quantity of electricity, in any state of intensity, easily and instantly passes.

Many important philosophical discoveries, which will be fully described in the article GALVANISM, have been already made, by means of the galvanic apparatus, in different parts of Europe; and a number of enlightened experimenters have been employed in investigating the principles on which its operation depends. The theory of it is, however, as yet obscure, and the perfect development of it will probably be connected with views more profound than any that have been as yet obtained of the nature and agencies of electricity, and its relations to chemical changes. See Phil. Trans. for 1800 and 1801. Nicholson's Journal, vol. iv. and v., and vol. i. new series. Journals of the Royal Inst. vol. i. Tilloch's Phil. Mag. vol. x. xi. and xii. Annalen der physik. Journal de physique. Annales de Chimie.

Benzoin

BENZOIN, *Benjamin Gum*, and *Benzoic Acid*, in *Chemistry and Pharmacy*.

The gum benzöin or benzöe, by some called also *Asa Dulcis*, is a very fragrant resin, procured from a large tree found in many parts of the East Indies, Sumatra, Arabia, Persia, &c. See STYRAX *Benzöe*.

The resin is brought in large brittle masses of a light yellow, interspersed with white nodules, which last are considered as the finest, and called by some *Benzöe Amygdaloides*. The smell of Benzoin is extremely fragrant, especially when

rubbed or heated : it has scarcely any taste, except previously dissolved in spirit of wine, which it does with ease, into a yellowish tincture. On adding water to this tincture, the resin again separates into a white pulverulent mass, which has received the singular name of *Lac Virginale*, and also *Magistery of Benzoin*. When gently dried, it forms a white powder, formerly in great request as a cosmetic. It is at least innocent, and its scent is one of the most agreeable. But the most striking ingredient of this resin is the

Benzoic Acid, which is of sufficient importance to require

Benzoic Acid, which is of sufficient importance to require being described more at large. If benzoïn is gently heated a little above the degree of boiling water, it melts into an adhesive mass, and at the same time sends out a very copious, dense, white fume, of an extremely fragrant, diffusive, penetrating smell, and so acid as irresistibly to excite coughing and tears in those who are in any degree exposed to it. This fume soon condenses on the first cool body, and then appears in the form of very beautiful spicular crystals, which gradually collect into a bulky feathery mass, extremely light, and of remarkable elegance and lustre. This crystalline mass is the benzoic acid, and its acid property is proved by reddening litmus, neutralizing alkalies, and forming with them peculiar salts; in modern chemical nomenclature called *Benzoates*. After the greater part of the acid has risen by sublimation, or before it, if the heat be at all increased, a thin yellowish oil rises slightly empyreumatic, but strongly imbued with the fragrance of the resin. On further heating, an acidulous liquor comes over, together with a thick butyraceous matter; still, however, containing some of the crystallizable acid, which is not totally expelled till the end of the process.

This acid is readily soluble in alcohol, and in hot water, but so sparingly in cold water, that a hot saturated solution will deposit in crystals almost its saline contents by cooling.

Several methods have been devised for obtaining the benzoic acid. The oldest and most expeditious is by simple sublimation. To perform any quantities of it, put benzoïn in an earthen pipkin; apply to the vessel a large cone of clean white paper, patted down to the edges of the pot, and set it over an extremely slow charcoal, or other fire, just sufficient to melt the benzoïn. The acid will rise and crystallize upon the inside of the paper cone. However, as in this method the vapour has hardly room to congregate, instead of the paper cone, another vessel inverted over that which contains the resin, and with a small hole drilled through its bottom, may be substituted; and when full, it may be gently shaken, to detach the acid, and again applied. From nine to twelve drachms may be thus obtained from sixteen ounces of benzoïn. The remaining resin is still very aromatic, and should not be lost.

Another method has been recommended by Scheele, who in his excellent practical observations upon this salt, has treated it with that precision and ingenuity which so eminently distinguish this chemist in every subject, of greater or less importance and difficulty, which he has illustrated by his labours.

He observes, that besides sublimation, the acid may be extracted by lixiviation, and with the advantage of obtaining it free from any admixture of oil, which is apt to impair its whiteness and lustre. If benzoïn is boiled with water, and the solution strained while hot, and suffered to cool, most of the acid taken up by the hot water deposits when cold, and may then be collected pure. This method, however, is imperfect; for as the water does not mix with and divide the gum, this last soon softens, and sinks down, closely adhering to the bottom of the vessel, and does not allow of the water easily to penetrate it. Hence the solution takes place only at the surface of the benzoïn.

The same chemist boiled powdered chalk and benzoïn in water, and filtrated the liquor. No crystals were now deposited on cooling, for the acid had dissolved part of the chalk into a benzoate of lime, which, being very soluble, remained in the liquor. But on adding some drops of vitriolic acid, the benzoic acid was again separated from the lime, and fell to the bottom in a powdery form. Substituting alkali for the chalk, the same effect took place, and the benzoic acid, as

before, was precipitated by the vitriolic. But this method was still attended with the inconvenience of the benzoïn concreting together, which floated on the surface during the boiling. But on substituting quick lime this inconvenience was avoided; and it is therefore in the following method that the benzoic acid may be procured the most copiously and the purest. Upon four ounces of unslacked lime pour twelve ounces of water, and after the ebullition is over, add six pounds more of water; then put a pound of benzoïn, finely powdered, into a tin pan; pour on it at first about six ounces of the above lime water; mix them well together, and then successively the rest of the lime water. By this method the resin will be prevented from running together into one mass. Boil the mixture for half an hour, with constant stirring, then let it stand, and pour off the clear liquor. On the remainder in the pan, pour more lime water, and proceed as before, adding the clear liquor to that first obtained, and also filter the residuum, to exhaust the liquor, which is now a weak solution of benzoic acid, with the lime of the lime water. Boil down this liquor (which is of a light yellow) to two pounds, and strain. When cold, add to the liquor muriatic acid gradually, which will produce a white crystalline deposition, and continue to add the acid till the liquor is supersaturated, and tastes sourish. The stronger acid thus unites with the lime, and the benzoic acid, now free, being of itself scarcely soluble in cold water, falls down as a white coagulum, which should be washed with more cold water, and gently dried. To give it a crystalline appearance, dissolve it in boiling water, filter it through a cloth, and by cooling it will separate in the form of spicular crystals, but with some loss of the acid.

The above process of Scheele's may however be a little shortened, if the lime in substance be mixed with the lime water, previous to the addition of the benzoïn; for by this method the solution may be at once made more concentrated, and less of the liquid will suffice, so that much of the evaporation will be saved. Any of the stronger acids will displace the benzoic from lime, but the muriatic is the most convenient.

Scheele obtained from 12 to 14 drachms of the concrete acid from a pound of benzoïn by this process.

The benzoic acid, when pure, is quite white; for if yellow, it is mixed with a small portion of the oil of the resin. Though crystallized, it is considerably elastic, and difficult to be reduced to powder. Its taste is sharp, pungent, and acidulous. It reddens tincture of litmus. When cold, it is without smell, but on applying heat it sends forth the peculiar grateful odour by which it is characterized. Heated by itself, it chiefly sublimates, but a part is decomposed, giving an acid phlegm, much oil, and carburetted hydrogen gas. It is not alterable in the air, and does not evaporate by keeping in a moderate temperature. Cold water dissolves only about $\frac{1}{15}$ of its weight, but boiling water $\frac{1}{5}$; and hence the copious crystallization from a hot water solution. It unites readily to most of the alkalies and earths forming benzoates, the properties of which have been but little examined.

The benzoate of lime is almost the only salt of this kind found native. It is contained in the urine of some animals, particularly the herbivorous quadrupeds, and is ascertained by adding to this secretion some muriatic acid, by which the benzoic acid is made perceptible.

With potash this acid forms a readily crystallizable salt, decomposable, like the rest of the benzoates, by a strong acid.

Most of the metallic oxyds are dissolved by this acid, but not the pure metals.

Mr. Hermbstadt, in a series of experiments on the action of nitrous acid on the benzoic, found that the latter regularly assumed in the process a smell like that of water distilled over

bitter almonds, but on the whole, this acid is but with difficulty altered in its nature by the nitrous. Distilling the nitro-benzoic acid with pure alcohol, he obtained ethereal liquor, part of which was nitrous ether, but the remainder appeared, by the smell of almonds, to be a dulcified, or ethereal benzoic acid. But these experiments require to be repeated with accuracy, as the powerful operation of the nitric acid on vegetable matter, though highly instructive, is often not a little embarrassing.

Several other substances, besides the resin of benzoin, contain more or less of this acid. The balsam of Peru, and of Styrax, appear to owe to this acid much of their fragrant smell. Ambergris, vanilla, and some of the aromatic barks, and even urine, contain a small quantity of it. When uncombined with an alkaline or earthy base, it is generally known by a pungent fragrant smell, and dense white smoke, on applying a heatless than is necessary to burn or decompose the substance with which it is united. When kept down by an alkali or an earth (as in the case of urine), it is separated by a strong acid. It has been supposed, with probability, that the fragrant scent is not proper to the acid, but is owing to the

presence of a portion of resin or essential oil, combined with it so intimately as to be inseparable by any means hitherto known, without entire decompositions of the acid; and hence too may be explained the very weak affinity of this acid for all bases, which is generally superior to no acid but the carbonic.

Gum benzoin is almost disused in medicine, though still retained in a few preparations of the London and Edinburgh pharmacopœias. The compound tincture *Tinctura Benzœis Composita*, formerly *Balsamum Traumaticum*, contains gum benzoin, balsam of Tolu, and aloes; and the benzoic acid enters into the Edinburgh *Tinctura Opii Ammoniata*, and in some other compounds of foreign dispensaries.

The fragrance of this resin has caused it to be used in fumigations of various kinds. Where the object is merely to produce a penetrating agreeable scent, it may be of considerable use; but as a *corrective* of foul or contagious air, its powers are very small, by no means comparable to those of the mineral acid vapours, while the irritation which it gives to the lungs is more intolerable. Scheele's Essays. Fourcroy. Hermbstadt in J. Phys. tom. 34, &c.

Bevel

BEVEL, in *Masonry*, and among *Joiners*, a kind of square, one leg whereof is frequently straight, and the other crooked, according to the sweep of an arch or vault ; being also moveable on a point, or centre, so that it may be set to any angle. The make and use of the bevel are pretty much the same as those of the common square or mitre, except that these latter are fixed ; the first at an angle of ninety degrees, and the second at forty-five ; whereas the bevel, being moveable, may, in some measure, supply the office of both, and yet, which it is chiefly intended for, supply the deficiencies of both, serving to set off or transfer angles, either greater or less than ninety or forty-five degrees.

Bricklayers have also a bevel, by which they cut the under sides of the bricks of arches straight or circular, to such oblique angles as the arches require, and also for other uses.

BEVEL, *Graduated*, is that which has about the centre of one of its arms a semicircle graven, and divided into 180 degrees, whose diameter stands square with the sides of the same arm ; so that the end of the other arm, being divided at right angles, almost to the centre, shews by its motion the number of degrees contained in the angle to be measured. This is also called *recipiangle*, and *pantameter*.

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The *simple Bevel* (see *Plate II. Geometry, fig. 35.*) consists of two rulers moveable on a common centre, like a carpenter's rule, with a contrivance to keep them fixed, at any required angle. The centre C must move on a very fine axis, so as to lie in a line with the fiducial edges CB, CD of the rulers, and project as little as possible before them. The fiducial edges of the legs represent the sides of any given angle, and their intersection or centre C, its angular point. A pin, fixed in the lower ruler, and passing through a semicircular groove in the upper, serves, by a nut A, which screws upon it, to fix the rulers, or legs, when they are placed at the desired angle.

The use of this instrument may be illustrated in the following examples :

1. Let 3 points, A, B, C, be in the circumference of a circle, which is too large to be described by a pair of compasses ; and let it be required to find any other number of points in the same circumference. Bring the centre of the bevel to B (*fig. 36.*), the middle point of the 3 given ones A, B, and C, and holding it there, open or shut the instrument till the fiducial edges of the legs lie upon the other two points, and fix them there by means of the screw A (*fig. 35.*) : this operation is called *setting* the bevel to the given points. Then removing the centre of the bevel to any part between B and A or C, the legs being at the same time kept upon A and C, that centre will describe, or be always found in, the arc which passes through the given points, and will thus ascertain as many others as may be required between the limits of A and C. In order to find points without those limits, proceed in the following manner : the bevel being *set*, bring the centre to C, and mark the distance CB upon the left leg ; remove the centre to B, and mark the distance BA upon the same leg ; then placing the centre on A, bring the right leg upon B, and the first mark will fall upon *a*, a point in the circumference of the circle, passing through A, B, and C, whose distance from A is equal to the distance BC. Removing the centre of the bevel to the point *a* last found, and bringing the right leg to A, the second mark will find another point *a'* in the same circumference, whose distance *aa'* is equal to AB. By proceeding in this manner, any number of points may be found, whose distances on the circumference are alternately BC and BA. In the same manner, by making similar marks on the right leg, points on the other side, as at *c'* and *c''* are found, whose distances *Cc'*, *Cc''*, are equal to BA, BC respectively. Intermediate points between any of the above are given by the bevel in the same manner with those between the original points.

2. Three points, A, B, and C, being given, to draw a line from any one of them, tending to the centre of the circle, which passes through them all. Set the bevel to the three given points A, B, and C (*fig. 37.*) ; lay the centre on A, and the right leg to the point C, and the other leg will give the tangent AG'. Draw AD perpendicular to AG' for the line required. For BAE being = BCA, the angle EAC is the supplement to the angle ABC, or that to which the bevel is set ; hence, when one leg is applied to C, and the centre brought to A, the direction of the other leg must be in that of the tangent G'E.

3. Three points being given as before, let it be required to draw from a fourth given point D, a line tending to the centre of a circle passing through the first three points. On D (*fig. 38.*), with the radius DA describe an arc AK ; set the bevel to the three given points A, B, and C, and bring its centre, always keeping the legs on A and C, to fall on the arc AK, as at H ; on A and H severally, with

any convenient radius, strike two arcs, crossing each other at I ; and the required line Dd will pass through the points I and D. For a line drawn from A to H will be a common chord to the circles AHK and ABC ; and the line ID bisecting it at right angles, must pass through both their centres.

4. Three points being given as before, together with a fourth point, to find two other points, such, that a circle passing through them and the fourth point, shall be concentric to that passing through three given points. Draw Ac and Cc tending to the centre, by a former problem ; set the bevel to the three given points A, B, and C ; bring the centre of the bevel to D, and move it upon that point till its legs cut off equal parts AN, CQ, of the lines Aa and Cc ; and N and Q will be the points required. For, supposing lines drawn from A to C, and from N to Q, the segments ABC and NDQ will be similar ones ; and consequently, the angles contained in them will be equal.

5. Two lines tending to a distant point being given, and also a point in one of them ; to find two other points (one of which must be in the other given line), such, that a circle passing through these three points may have its centre at the point of intersection of the given lines. Draw EH (*fig. 39.*) at right angles to AB, and make FH = FE ; set the bevel to the angle GDO, and keeping its legs on the points H and E, bring its centre to the line AB, which will give the point I.

An improved bevel is exhibited in *fig. 40.* by which the arcs of circles of any radius, without the limits attainable by a common pair of compasses, may be described. It consists of a ruler AB, composed of two pieces rivetted together near C, the centre or axis, and of a triangular part CFED. The axis is a hollow socket fixed to the triangular part, about which another socket, fixed to the arm CB of the ruler AB, turns. These sockets are open in the front for part of their length upwards, as represented in the section at I, which shews the point of a tracer, or pin, fitted for sliding in the socket. The triangular part is furnished with a graduated arc DE, by which and the vernier at B, the angle DCB may be determined to a minute. In this arc is a groove, by means of which, as well as by the nut and screw at B, or some similar contrivance, the ruler AB may be fixed in any required position. A scale of radii is put on the arm CB, by which the instrument may be set to describe arcs of given circles, not less than 20 inches in diameter. In order to set the instrument to any given radius, the number expressing it in inches on CB, is brought to cut a fine line drawn on CD, parallel and near to the fiducial edge of it, and the arms are fastened in that position by the screw at B. Two heavy pieces of lead or brass G, G, made in form of the sector of a circle, the angular parts being of steel, and wrought to a true upright edge, as shewn at H, are used with this instrument, whose arms are made to bear against those edges when the arcs are drawn. The under sides of these sectors are furnished with fine short points to prevent them from sliding. The fiducial edges of the arms CA and CD, are each divided from the centre C into 200 equal parts. This instrument might be furnished with small callipers, like the pentagraph ; but little buttons, fixed on its under side, near A, E, and D, will enable it to slide with sufficient ease.

The use of this instrument may be exemplified in the following problems :

1. To describe an arc, which shall pass through three given points.—Place the sectors G, G', with their angular edges over the two extreme points ; apply the arms of the bevel to them, and bring at the same time its centre C, that is, the point of the tracer, or pen, put into the socket, to the

arms constantly bearing against the two sectors, till it comes to the right-hand sector, by which the required arc will be described by the motion of its centre C. If the arc be wanted in some part of the drawing *without* the given points, find by case 1. under *simple bevel*, other points in those parts where the arc is required; and thus a given arc may be lengthened as far as is necessary.

2. To describe an arc of a given radius, not less than 10 inches.—Fix the arm CB so that the part of its edge, corresponding to the given radius, always reckoned in inches, may lie over the line drawn on CD for that purpose; being the centre to the point through which the arc is required to pass, and dispose the bevel in the direction in which it is intended to be drawn; place the sectors G, G, exactly to the divisions 100 in each arm, and strike the arc as above described.

3. The bevel being set to strike arcs of a given radius, as in the last instance, let it be required to draw other arcs, whose radii shall have a given proportion to that of the first arc. Suppose the bevel to be set for describing arcs of 50 inches radius, and it be required to draw arcs of 60 inches radius, with the bevel so set. Say, as 50 is to 60, so is the constant number 100 to 120, the number on the arms CA and CD, to which the sectors must be placed, in order to describe arcs of 60 inches radius. When it is said that the bevel is set to draw arcs of a particular radius, it is always understood that the sectors G, G, are to be placed at No 100 on CA and CD, when those arcs are drawn.

4. An arc ACB (fig. 41.) being given, let it be required to draw other arcs concentric to it, which shall pass through given points, e. g. P. Through the extremities A and B

of the given arc, draw lines Ap, Bp, tending to its centre, by case 3. under *simple bevel*. Take the nearest distance of the given point P from the arc, and set it from A to P, and from B to P. Hold the centre of the bevel on C, any point near the middle of the given arc, and bring its arms to pass through A and B at the same time, and fix them there. Place the sectors to the points P and P, and with the bevel, set as before directed, draw an arc, which will pass through P the given point, and be concentric to the given arc ACB.

5. Through a given point A (fig. 42.) in the given line, to strike an arc of a given radius, and whose centre shall lie in that line, produced if necessary. Set the bevel to the given radius, by case 2. Through A, at right angles to AB, draw CD; lay the centre of the bevel, set as above, on A, and the arm CA on the line AC, and draw a line AE along the edge CD of the other arm. Divide the angle DAE into two equal parts by the line AF, and place the bevel so that, its centre being at A, the arm CD shall lie on AF; while in this situation, place the sectors at No 100 in each arm, and then strike the arc.

6. An arc being given, to find the length of its radius.—Place the centre of the bevel on the middle of the arc, and open or shut the arms till No 100 on CA and CD, fall upon the arc on each side of the centre; the radius will be found on CB (in inches) at that point of it, where it is cut by the line drawn on CD. If the extent of the arc be not equal to that between the two Nos. 100, make use of the No 50, in which case the radius found on CB, will be double of that sought; or the arc may be lengthened by prob. 1. till it be of a sufficient extent to admit the two Nos. 100. Adams's Geometrical and Graphical Essays, by Jones, 1797.

Birmingham

BIRMINGHAM, is justly esteemed the greatest manufacturing town in England, and we may safely assert, that in the quantity, variety, elegance, and utility of its manufactured articles, it surpasses any town in Europe. To enable the stranger and foreigner to appreciate the general character of this place, with its various subordinate features, we will endeavour to depict them to the fancy, in a concise and perspicuous narrative. Its distinguishing characteristic is appropriately displayed in the following lines by Mr. Jago, in his poem of "Edge-hill."

" 'Tis noise, and hurry all.—the throng'd street,
The close pil'd warehouse, and the busy shop;
With nimble stroke the tinkling hammers move;
While slow and weighty the vast sledge descends,
In solemn base responsive, or apart,
Or socially conjoined in tuneful peal.—
How the coarse metal brightens into fame,
Shap'd by their plastic hands! what ornament!
What various use!—Nor this alone thy praise,
Thine too of graceful form, the letter'd type!
The friend of learning, and the poet's pride."

The etymology of the name of this town is not readily attained, as it has been written *Brumwycheham*, *Bromwy-cham*, and various other ways; indeed, in common conversation, it is frequently pronounced *Bromidgham*. The town lies near the centre of the island, in the north-western extremity of the county of Warwick. It is in the diocese of Lichfield and Coventry, in the deanery of Arden, and in the hundred of Hemlingford. The superficial contents of the parish are 2864 acres. In 1800 here were 16,403 houses, 1875 of which were uninhabited. The whole population was 73,670, of whom 34,716 were males, and 38,954 were females.

In the scale of national importance, Birmingham bears an exalted situation; without recurring to its ancient history, the modern inhabitants have, by laudable industry, raised it perhaps to the acme of manufacturing and commercial fame. The sagacious and elegant Burke emphatically pronounces Birmingham the "Toy Shop of Europe." This designation must not, however, be taken in its literal sense, as the articles of utility made in this town far exceed those intended only for show and ornament. Many of our cities are attractive for their venerable ruins and grand cathedrals, but of those Birmingham is destitute. The traveller, who delights in seeing the human race profitably employed to their own, and their country's advantage, will disregard the smoke which sometimes envelopes the town, and discern through the veil the bright beams of industry enlightening vast piles of riches: justice, however, will compel him to acknowledge, that profligacy has contrived to insinuate itself within too many dwellings of the labouring classes, producing idleness, discontent, drunkenness, and riots, of which several instances might be cited, exclusive of that grand convulsion which attended the commencement of that revolu-

tion in France, which in its consequences has so severely oppressed this, and almost every other nation. The Ikenild-street, one of the great Roman military roads, comes within a mile of Birmingham, and in Sutton park and Coldfield, four miles from the town, it remains nearly as perfect as if just completed; one of the principal evidences of the antiquity of Birmingham is, that it is contiguous to two Roman roads, the Ikenild, and Shirley streets.

The family of Birmingham were lords of this manor till 1537, at which period it is said to have been obtained by the duke of Northumberland, through the success of a deep-planned scheme. Having endeavoured in vain to purchase it, he contrived to make Edward Birmingham appear as an accomplice in a highway robbery, and offered him his interest to save a forfeited life, on condition of selling him the manor. The manor-house, which is now called the mote, still remains, though the site has been converted into a manufactory, and an apartment is shewn, where the ancient lords held their court-leets.

The parish of Birmingham is smaller than any in its neighbourhood. Mr. Hutton observes, that when Alfred founded a town, he allotted a much smaller space of land to it, than when he portioned a village, obviously intending the former for trade and commerce, and the latter for agriculture; this circumstance seems to prove that Alfred found Birmingham a town. "The buildings occupy the south-east part of the parish, which, with their appendages, are about 800 acres. This part being insufficient for the extraordinary increase of the inhabitants, she has of late extended her buildings along the Bromsgrove road, near the boundaries of Edgbaston, and on the other side planted some of her streets in the parish of Aston."

"The situation is elevated, and the soil one solid mass of dry, reddish sand, through which the water descends freely, thus making even the cellars comfortable habitations;" the same author adds facetiously, that though metals of various sorts are found in great plenty above the surface, we know of nothing below except sand, gravel, stone, and water. All the riches of the place, like those of an empiric in laced clothes, appear on the outside. "There is not any natural river in the parish, but in the lower parts of the town are two excellent springs of soft water, suitable for most purposes, one at the top of Digbeth, the other Lady well; and at the latter place are seven of the most complete baths in the kingdom. They cost 2000 *l.* in erecting, and are ever ready for the accommodation of hot or cold bathing, for immersion or amusement, with conveniency for sweating. That appropriated to swimming is 18 yards by 36, situate in the centre of a garden, in which are 24 private undressing houses, and the whole surrounded by a wall ten feet high."

Mr. Hutton mentions several instances of longevity, which seem to demonstrate either that the air is too pure to be rendered unwholesome by the smoke of the town, or that smoke

smoke and steam are not so prejudicial to health as have been imagined : his instances are one person aged 100, a second 103, a third 104, and a fourth 107, four upwards of 90, and 13 upwards of 80.

Birmingham is not a place a gentleman would chuse to make a residence. Its continual noise and smoke prevent it from being desirable in that respect.

Many ancient families who once flourished at and near Birmingham, are mentioned by Mr. Hutton to have fallen into irretrievable decay ; one instance is worth transcribing. "We have among us a family of the name of Middlemore, of great antiquity, deducible from the conquest ; who held the chief possessions, and the chief offices in the county, and who matched into the first families in the kingdom, but fell with the interest of Charles I., and are now in that low ebb of fortune, that I have frequently, with a gloomy pleasure, relieved them at the common charity board of the town."

It appears upon record, that in 1251, William de Birmingham, lord of the manor, procured an additional charter from Edward III. reviving some decayed privileges, and granting others ; among the last was that of the Whitsuntide fair, to begin on the eve of Holy Thursday, and to continue for four days. At the alteration of the style in 1752, it was prudently changed to the Thursday in Whitsun week, that less time might be lost to the injury of the manufacturers and their workmen. The same person also procured another fair, to begin on the eve of St. Michael, (which is commonly called the Onion fair, on account of the great quantity of onions sold at the time) both of which are at this day in great repute. The horse fair, which formerly was kept in Edgbaston-street, was, in 1777, removed to Brick-kiln-lane ; and that for beasts, which used to be in the High-street, into Dale end, in 1769.

Near Birmingham, on the London road, is Camp-hill, where the army of prince Rupert were encamped, during the siege in 1643. The inhabitants are accused of disloyalty by lord Clarendon, for seizing the carriages which contained the royal plate and furniture. The prince, with 2000 men, had been commanded by the king to open a communication between Oxford and York, but the hardy and imprudent inhabitants of this town dared to oppose this force, with only a company of foot, and a troop of horse. Though they had thrown up some slight works, and blockaded the streets, yet the king's army forced through these trifling obstructions, and entered the town sword in hand. The earl of Denbigh, a royalist, was killed in this affair, as was a clergyman who acted as governor for the parliament, and who refused quarter. Birmingham had a narrow escape from destruction, for the exasperated commander ordered the place to be burnt, but some favourable circumstance confined the conflagration to a few houses in Bull-street.

The plague of 1665, was imported into the town in a box of cloaths brought to the White Hart inn. Hence the fatal poison insinuated itself through the streets and houses, destroying great numbers of the inhabitants, whose bodies soon filled the church-yard, and also an acre of land at Ladywood green, which was afterwards called the Pest-ground.

Although some degree of eminence attached to Birmingham previously to the reign of Charles II., yet it is from that period that its rapid increase must be dated. Building leases then became common, and numbers of houses arose to accommodate the increasing population which assembled, in consequence of the cultivation of the mechanical arts.

About the year 1700, the number of streets in Birmingham

was only 30, but now there are nearly 250 ; besides, several of the oldest are considerably improved and augmented. This will, in some measure, assist the imagination in comprehending the amazing increase of the town in size, wealth, and manufactures, during that time ; and it is no presumption to suppose, that it has not yet arrived at its zenith ; one instance of increase will be sufficient to point out the general improvement. Between the roads to Wolverhampton and Dudley, there were only three houses March 14, 1779. By that day twelve months they increased to 55, and March 14, 1781, there were 144. The same day in 1791, there was an addition of 833.

Thomas Sherlock, bishop of London, purchased of the ladies of the manor in 1730, land worth 400l. per annum ; in 1758, the income was doubled. He always refused to let it on building leases, alledging, that his successor would be compelled to remove the rubbish at the expiration of the terms ; sir Thomas Gooch, who held the land after the above prelate, procured an act about 1766, for setting aside the prohibitory clauses of the bishop's will ; immediately let the ground, and improved the rents to 2400l. per annum ; it appears from the books of the poor-rates, that less than 5000 houses pay the parochial dues, and more than 8000 houses are exempt ; this fact denotes the prevailing description of population.

Manufactures, &c. The extraordinary increase in the size, population, and prosperity of Birmingham, arises principally from its proximity to the coal mines, from the nature of the soil, from its canals, from the successful exertions of a few individuals in some manufacturing speculations, and from its being exempt from borough, and corporate laws and restrictions. To investigate and detail the whole of these causes, with their effects, would occupy more space than we can consistently appropriate. The most prominent characteristics, however, shall be narrated. To the late John Taylor, esq. a man of great industry and ingenuity, the public are indebted for the gilt button, the japanned and gilt snuff-box, with the numerous class of enamels ; also the painted snuff-box, at which employ, one servant earned 3l. 10s. per week, by painting them at a farthing each. In his shops were weekly manufactured buttons to the amount of 800l. exclusive of other valuable productions, and eighty guineas have been given him for a single toy made at his shop. He died in 1775, at the age of 64, after acquiring a fortune of 200,000l. His son is now partner in one of the largest provincial banking houses in England.

The greatest and most noted manufactory of this place, and perhaps in Europe, is that at Soho, about two miles from Birmingham. This is the property of Messrs. Boulton and Watt, who have advanced certain pieces of mechanism and productions of art to a state of excellence, that have excited the astonishment and admiration of nations. The large warehouses, work-shops, and the elegant mansion of the former gentleman, cover the declivities of a hill, which a few years back was a barren heath, tenanted only by rabbits, and a warreners hut ; now this once desolate scene is converted into an emporium of arts and beauties. Such are the wonderful powers of human ingenuity and industry. In 1757, this spot, with some contiguous land, was leased for 99 years, to Messrs. Roston and Evans, who erected a house and a mill for rolling metal, &c. At Lady day 1762, Mr. Boulton bought the whole, and removing to it soon afterwards from Birmingham, commenced the present extensive premises, which were nearly completed in 1765, at an expence of 9000l. He now admitted a partner, Mr. Fothergill, into the concern, and

established an extensive correspondence throughout Europe. To obtain and support a reputation, every encouragement was afforded to men of genius in drawing, modelling, and other branches of the arts. An imitation of or molu in vases, tripods, and candelabras, was adopted, accompanied by so much skill and elegance, that universal approbation followed; this led to the manufacture of wrought silver, and an application was made to parliament in 1773, for an assay office, to be established at Birmingham. The poly-graphic art had its origin at Soho. This method of copying pictures in oil, by a mechanical process, was conducted by F. Eginton, who has since executed a great number of fine specimens of painting, or staining of glass. The encaustic mode of staining glass, or fixing the vivid and fine graduating colours upon that transparent material, was supposed to be lost, but it has been revived and brought to great perfection by this gentleman. Since 1784, he has executed several large windows for various cathedrals, churches, and gentlemen's mansions. (See GLASS PAINTING.) Among the various machines, &c. invented and constructed at Soho, there is one entitled to distinguished notice for its great national utility and importance. This is the *steam engine*, which has acquired extraordinary force and improvements by Mr. James Watt, one of the proprietors of the Soho firm. To him the scientific world is much indebted for various other inventions and improvements in mechanics. With a vigorous comprehensiveness of mind, he embraces every mathematical and mechanical subject from the simplest to the most complex and profound. He procured a patent for the steam engine in 1768, and seven years afterwards, entering into partnership with Mr. Boulton, began to construct those machines at Soho. Since that period, they have been generally adopted in the mines and manufactories all over the kingdom. (See STEAM ENGINE.) The following list of curious and useful articles are manufactured at these works, which, when fully employed, give support to upwards of 600 labourers. Buttons of all kinds; polished steel, and jetina steel-toys; polished steel watch chains; patent cork-screws, &c. Buckles and lachets of all sorts; plated and silver goods for the dining and tea-table, side-board, &c.; medals and coins of various sizes and metals. The late beautiful new coinage of copper, and also the re-stamped dollars; all come from the Soho mint. The coining mill or engine first erected here in 1783, has been much improved since that period, and is now adapted to work eight machines at once, each of which will strike from 70 to 84 pieces per minute, the size of a guinea; or between 4,000 and 5,000 per hour. Thus the eight machines will work between 30,000 and 40,000 coins in one hour. These machines are operated on by the steam-engine, and perform the following processes: 1st. rolling the masses of copper into sheets; 2nd, fine rolling of the same cold, through cylindrical steel rollers; 3rd, clipping the blank pieces of copper for the die; 4th, shaking the coin in bags; 5th, striking both sides of the coin, and milling it, at the same time displacing it, and placing another for the same operation. To its other properties, this ingenious machine adds the almost magical one of preventing fraud, by keeping an accurate account of every coin which passes through it. Dr. Darwin has described this singular apparatus in the following apposite poetical lines:

—“Now his hard hands on Mona's rested crest,
Bosom'd in rocks, her azure ores arrest;
With iron lips his rapid rollers seize
The lengthened bars in their expansive squeeze;
Descending screws with pond'rous fly-wheels wound

The tawny plates, the new medallion's round;
Hard dies of steel, the cupreous circles cramp,
And with quick fall, his maffy hammers stamp.
The harp, the lily, and the lion join,

And George and Britain guard the splendid coin.”

Relled metals of all kinds of mixtures, are prepared here; besides pneumatical apparatus, large and portable; also copying machines, and in short, almost every sort of article for use or ornament.

Besides the manufactories already named, Birmingham contains several others, which are entitled to our consideration; and although we cannot allow space for particulars, yet we must not pass them altogether unnoticed.

Messrs. Richards's in High-street, is styled the toy-shop of Birmingham; the elegance and variety of the articles are not to be equalled, with the exception of the show-room at Soho. Mr. Clay's japan manufactory is not less celebrated, particularly when it is considered that the japan is fixed on common brown paper. To those may be added Clarke and Ashmore's manufactory of whips. Gill's gun, bayonet, and sword manufactory, supposed to be one of the best in the world; and Galton's for sporting guns. Previous to the reign of William III. guns were mostly imported from Holland; but that monarch having once expressed some regret at this circumstance, and deplored the necessity of sending abroad for the article, Sir Richard Newdgate, M.P. for Warwickshire, being present, assured the king that his constituents would undertake to supply the demands of government. An order was given, and being readily and correctly executed, Birmingham has continued from that period to be the great and principal place of manufacture for this destructive weapon. See GUN.

Leather appears to have been manufactured here in great quantities in the early periods of the history of Birmingham; but in 1795, there was but one tanner in the place.

Within the last century, the manufacture of steel into almost every kind of toy and ornament took its rise: a large street bears the name of Steel-house-lane, from the extensive works carried on there. Here are also very large brass works erected on the banks of the canal, on the road to the five ways, near which stand the ruins of the mansion built by the late John Baskerville, who made great improvements in the art of printing. See BASKERVILLE.

Places of Amusement and Curiosity. In New-street is a museum, or repository of natural and artificial curiosities, the property of J. Bisset, a gentleman who has published some ingenious poems and useful books. His “Magnificent Directory,” is a novel, handsome, and useful work, in which are contained elegantly engraved, emblematical cards of address of a great number of the merchants, manufacturers, tradesmen, &c. throughout England.

The first Theatre established at Birmingham was situated in Moor-street about 1740; that in King-street was erected 1765, and enlarged 1774; in the same year it was transferred to a religious society; and another built in New-street, at an expence of 5660*l.* and managed with great success by Mr. Yates. In 1791, it was burnt by some incendiaries, who have never been discovered; since that period, the proprietors have rebuilt it in a very splendid manner for 14,000*l.* with an assembly room and a tavern annexed to it. Mr. Macready of Covent Garden theatre, is the present manager, who generally presents his audiences with the best London performers during the summer months. Concerts and musical parties are held weekly during winter; and the summer produces a variety of public gardens, the principal of which are Vauxhall and Spring-gardens.

Government. Birmingham is governed by three acting magistrates; the officers chosen annually are the high-bailiff, who inspects weights and dry measures, and the markets; the low-bailiff, who summons juries, and chuses all the other officers; two constables and one headborough; two high tasters, who examine the quality of beer and its measure; two low tasters or meat conners, who inspect the meat exposed to sale, and cause that to be destroyed which is unfit for use; two afficers, and two leather-sellers, whose offices are now only nominal.

Deritend, a hamlet of Birmingham, sends its inhabitants to the court leet of that town, where all the above officers are chosen and sworn, in the name of the lord of the manor.

An act of parliament passed in 1752, which established a *Court of Requests*, consisting of 72 commissioners, three of whom are a quorum; they sit every Friday morning in a room of the Red Lion inn; the clerks attend to give judicial assistance, who are always professors of the common law, and chosen by the lord of the manor and the commissioners for life: ten of the commissioners are ballotted out every other year, and ten others elected from among the inhabitants. The beneficial effects of a humane society for the recovery of suspended animation were first extended to Birmingham in 1790. About the same period a committee of respectable inhabitants was established to watch over the common interests, under the title of the "Commercial Committee."

In 1791, W. Villars, esq. then high bailiff, opened a market for haw, straw, &c.

A public library was founded in 1779, which has flourished greatly, and contains nearly 10,000 volumes, supported by upwards of 500 subscribers. An elegant pile of building was erected in Withering-street for the purposes of the institution in 1797. A rival made its appearance in 1796, with every prospect of success; besides those, there are medical and law libraries, and many reading societies. Birmingham contains two churches, and four chapels; besides several meeting houses.

Churches. St. Martin's church, denominated the Old church, was raised previously to the year 1300. It is of stone, and occupies the site of, or is the first sacred building belonging to the place. In 1690, it was thought necessary to case the church and tower with brick. The walls support the arms and monuments of several titled and ancient families. Under the south window are two of white marble, one of which is supposed to have been erected for William de Birmingham, who was captured by the French at the siege of Bellegard in 1297. He wears a short mantle, &c. and bears a shield with the bend lozenge. This church was repaired and altered in 1786, at an expence of 4000l. The patronage belonged to the family of Birmingham till 1537, since which period it has been possessed by the Dudleys, the crown, the Marrows, the Smiths, and finally the Tenants. The rectory was valued in the king's books 1291, at 5l. per annum, and in 1536, at 19l. 3s. 6d. The income is now upwards of 1000l. and expected to be 2000l. after the expiration of certain leases.

St. Philip's, or the *New church*, is a handsome pile of building, but how Mr. Hutton or any other person could fancy and say that the steeple is erected after "the model of St. Paul's in London, but without its weight," is to us inconceivable, as there is not a line of it that reminds the spectator either of the dome or turrets of the metropolitan edifice. It must be allowed that the tower of St. Philip's finishes with an attic and a diminutive cupola, but there ends the resemblance. This church is advantageously situated on an eminence, and the site was given by Robert Philips, esq.

It was begun by act of parliament in 1711, under a commission consisting of 20 of the neighbouring gentry appointed by the bishop of the diocese under his episcopal seal. In 1715, it was consecrated, and finished in 1719, at the real cost of only 5012l. though the estimated value was nearly 20,000l. This circumstance arose from the gift of materials, &c. The church-yard consists of four acres, and is intersected by handsome walks, shaded by trees in double and treble rows, and is surrounded by elegant buildings. Two thousand persons may be conveniently accommodated in St. Philip's church, which has contained nearly 3000. William Higgs, first rector, founded a theological library for the use of the neighbouring clergy, and bequeathed 200l. to augment it. The Rev. Spencer Madan erected a room in 1792, adjoining the parsonage, and termed it the parochial library. The rectory is worth about 300l. per annum.

St. Bartholomew's Chapel, capable of containing 800 persons, was erected in 1749, on a site given by John Jenneus, esq. an opulent land-holder of Birmingham. Mrs. Jenneus, through the good offices of Mrs. Weaman, added 1000l. and the remaining sum was received in contributions from pious inhabitants. The chapel and tower are handsome, and the former presents a line north and south. The altarpiece is the gift of Basil, earl of Denbigh, and the communion plate that of Mary Carless.

St. Mary's Chapel was erected in 1774; on a spot of ground given by Mary Weaman, whose family has the patronage. The incumbency is valued at 200l. per annum.

St. Paul's Chapel is a stone building erected in 1779, by virtue of the same act which founded St. Mary's. Charles Colmore, esq. gave the ground; a steeple is intended, and the east window was decorated in 1791, with painted glass, representing the conversion of St. Paul, by Francis Eginton, who received 400 guineas for the same.

The house of a celebrated physician of Birmingham, Dr. Ash, was purchased in 1789 by an attorney, who converted it into an elegant chapel, at the expence of his own ruin, where he caused the service of the church to be chanted by a numerous choir, accompanied by an organ. Dr. Croft, and some other clergymen, afterwards purchased it, and engaged to officiate there regularly. The congregation chiefly consists of soldiers from the neighbouring barracks.

Dissenting Meeting Houses. *Old Meeting-street* received its name from the old meeting erected in the reign of William III. which was destroyed in 1791 by the mob. The trustees recovered 1390l. 7s. 5d. damages, and rebuilt the present building, at an expence of 5000l.

The *New Meeting* built 1730, shared the fate of its parent in 1791, and has never been rebuilt. The celebrated Dr. Priestley presided over the spiritual concerns of this place of worship at the period of its destruction, and narrowly escaped personal injury, or perhaps death, from the furious populace. He fled, and finally retired into exile, within the state of Pennsylvania, where he died 1804, with the fame of an excellent philosopher and experimentalist. (See PRIESTLEY.) The trustees having lost their licence, could not recover damages, but the king granted his warrant upon the treasury for 2000l.

The *Union Meeting* in Livery-street, originally an amphitheatre for the exhibition of equestrian exercises, being unoccupied at the period of the riots, the congregations of the two meetings hired, and converted it into a place of worship. After the re-erection of the old meeting, they separated, resigning the Union meeting to the new

assembly, who occupy it till their place of worship is re-built.

Carrs-Lane Meeting, a kind of chapel to the old meeting, was erected in 1748. This society has 800*l.* bequeathed by John England in 1771, and 40*l.* 18*s.* per annum, termed Scott's trust.

A *Baptist Meeting* in Canon-street, was founded in 1738, and has continued prosperously to the present period.

The *Quakers* have a meeting in Bull-street, frequented by a large, peaceable, and rich congregation; behind it is a spacious burial-ground. The methodists are now very numerous; previous to 1782, there was but one congregation, whose place of worship had been a theatre; whence they removed to a splendid meeting in Cherry-street, erected at an expence of 1200*l.* John Wesley, their chief priest, preached in it for the first time July 7, in the above year; three others have since been erected and purchased in Colehill-street, Deritend, and Newhall-street. The last was erected as a new Jerusalem temple, for the Swedenborgians, but in too magnificent a style for their revenues. The methodists bought it, and the original possessors built a smaller temple.

A small *Roman Catholic Chapel* is situated at Eady-hill, in the place of one destroyed during the destructive riots. A Jewish synagogue, a baptist's meeting, and an independent meeting, lady Huntingdon's meetings, and some other places of worship, are found in this town, which, like most manufacturing places, is distinguished for its number of dissenters of different sects.

Charities. Some of the streets of Birmingham are kept in repair by emoluments arising from small estates. William Lench, who lived in the reign of Henry VIII. bequeathed certain estates to the town, in trust to sixteen inhabitants, for repairing the streets. This person founded the almshouses in Steel-house lane for poor widows. Fentham's trust is 100*l.* per annum, and applied to teaching poor children reading, and for cloathing ten poor widows. The date of the donation is 1712. Mr. Crowley gave in 1733, six houses for the support of a school for ten girls.

The *Free School* was erected on the site of the guild of the holy cross, which had an endowment of lands for the maintenance of two priests, worth twenty marks per annum, given by Thomas de Sheldon, John Colehill, John Goldsmith, and William Attislowe. In 1303, the bailiff and inhabitants obtained a patent for augmenting the foundation, and adding a brotherhood, which flourished till the general dissolution, and was then valued at 31*l.* 2*s.* 10*d.* per annum. Edward VI. granted the lands belonging to the guild in 1552, at the suit of the inhabitants to nineteen persons, as bailiff and governors of the free grammar school of king Edward VI., to hold in common soccage at a rent of 20*s.* per annum. Their successors erected the present building in 1707, which is large and handsome, has a neat tower in the centre, and a statue of Edward VI. in front. The chief master's salary is 120*l.* the second 60*l.* two ushers 40*l.* each for writing and drawing, and a librarian 10*l.* There are seven exhibitions of 25*l.* per annum each for the university of Oxford, and the possessions are valued at 1200*l.* per annum.

The *Blue Coat School* was erected 1724, but enlarged and improved in 1794, at an expence of 2500*l.* The revenues are 1327*l.* and 150 boys and 40 girls receive the benefits of the institution.

The *Dissenter's Charity School* was held at the old meeting, but after that was destroyed, a building was purchased in Park-street, and has been much improved. The children received are 40 boys and 20 girls.

The *Work-house* erected 1733, cost 1173*l.* a wing was added for an infirmary 1766, and another in 1779, at an expence

of 1100*l.* The inhabitants pay a rate of 6*d.* in the pound, which raises 17,000*l.* per annum, and relief is afforded to 7000 persons. There are twelve overseers.

The *General Hospital* was erected 1766, and two wings were added 1791. It is supported by voluntary contributions, and many large bequests; the physicians generally give their assistance gratis.

The *Prisons* in Peck-lane and Deritend are disagreeable and unwholesome, and both are licensed as public houses.

The *Canal* between this place and Wednesbury, was made in consequence of an act obtained in 1767. It is twenty-two miles in length, uniting with the Staffordshire canal; the shares were 140*l.* each, and the expence 70,000*l.*; they fold in 1782 for 370*l.* each, and in 1792 for 1170*l.* Sir Thomas Gooch leased the proprietors six acres of land at 47*l.* per annum, which they converted into a wharf, and erected a handsome office on it. The boats are drawn by one horse, and are about twenty-five tons burthen. Coals are little more than half the price they were before this canal was made. Several other canals, equally beneficial, have since been completed, opening a communication between this town, and almost every principal town in the kingdom.

The *Barracks* stand on five acres of land, held by government at one penny per yard. They were erected in 1793 for 13,000*l.*, and will accommodate 162 men.

There are three extensive Breweries near Birmingham, Richards's in Deritend for ale, Giles and Norrefts, Writtonelane, for ale and porter, and the Britannia, Walmer-lane, belonging to Clay and co.

The riots, already alluded to, constitute an unpleasant feature in the history of this town, and whilst they serve to characterize the folly and infatuation of the lower classes of society, will, we trust, operate as a warning example to the rising generation. A few persons assembled at the hotel Birmingham, July 14, 1791, to celebrate the anniversary of the French revolution. A mob collected round the house, broke the windows, and immediately proceeded to Dr. Priestley's new meeting. This, and the old meeting, were soon burnt to ashes, and the doctor's house and furniture, with his valuable library, apparatus, and MSS. shared the same devastating fate. On July 15, the mansions of John Ryland, esq. at Eady-hill, and Bordesley-hall, the seat of John Taylor, esq. together with the house, stock in trade, books, furniture, &c. of Mr. Hutton, author of the "History of Birmingham," were destroyed. Saturday the 16th witnessed the destruction of Mr. Hutton's house at Saltley, the residences of George Humphreys, William Ruffel, and John Taylor, esqrs. The latter, Bordesley-hall, was occupied by lady Carhampton, mother to the duchess of Cumberland, but neither her blindness through age, nor connection with the king, could prevent the mandate of removing her furniture from the mob, who frantically offered to assist: "She was therefore, like Lot, hastened away before the flames arose, but not by Angels." The reverend Mr. Hobson's and Mr. Harwood's houses were next burnt; those of the Rev. Mr. Coates, Mr. Hawkes, and Thomas Ruffel, esqrs. were plundered. On Sunday the 17th, Kingwood meeting perished in flames, the parsonage-house, and that of Mr. Cox, licensed for public worship. The mob this day plundered Edgbaston-hall, Dr. Withering's, and attacked Mr. Male's house, but hearing in the evening, that a troop of horse approached, they gradually dispersed, after destroying property to the amount of 60,000*l.* To reimburse the sufferers, an act was obtained in 1793. The war succeeding, greatly injured Birmingham, and this cannot be more

clearly proved than by referring to the 1875 uninhabited houses in the year 1800. There are two morning papers published at Birmingham; Aris's Birmingham Gazette, and Swinney's Birmingham Chronicle, &c. Mr. Swinney also carries on a considerable type foundery, which is the only provincial one in the kingdom. "This neighbourhood," says Mr. Hutton, "may justly be deemed the seat of the arts, but not the seat of the gentry. None of the nobility are near us, except William Legge, earl of Dartmouth, at Sandwell, four miles from Birmingham. The principal houses in our environs are those of the late sir Charles Holte at Alston; sir Henry Gough Calthorpe at Edgbaston; George Birch, esq. at Handsworth; John Gough, esq. at Perry; and John Taylor, esq. at Bordesley and at Moseley, all adjoining to the manor of Birmingham; exclusive of these, there are many retreats of our first inhabitants, acquired by commercial success." Hockley Abbey, near Soho, is the residence of Mr. Richard Ford, an ingenious smith, who had the honour of presenting his majesty with an iron carriage made by himself. It is a modern curious building, with

the upper part representing a ruin, and is surrounded by beautiful grounds and walks, interspersed with fanciful curiosities. The most *considerable* seats in the vicinity of Birmingham, are Hagley, 12 miles distant; Enville, 18 miles distant; and the Leasowes, six miles distant. The latter will long be preserved in the memory of every reader of Shenstone, whose creation it was, and whose taste it displayed in an eminent degree. It now belongs to Charles Hamilton, esq. who has judiciously restored the neglected beauties of the place. Hagley, the seat of lord Littelton, has been particularly celebrated in the writings of Pope, Thomson, Hammond, and other poets. Enville, the seat of the earl of Stamford, is a scene of great natural beauty. For further particulars relating to Birmingham, its manufactures and neighbourhood, see Hutton's "Hist. of Birmingham," 8vo. Shaw's "Hist. of Staffordshire," fol. "A companion to the Leasowes, Hagley, and Enville," 12mo. Bisset's "Poetic Survey round Birmingham," 8vo. Philips's "History of Inland Navigation," 4to. &c.

Bismuth

BISMUTH, *Bismutum*, Wallerius; *Wismuth*, or *Bismuth*, Germ; *Bismuth*, Fr.; *Plumbum cinereum*, *Antimonium femininum*, *tin-glass*, of the older chemists.

Bismuth is a brittle metal, of a reddish white colour, and foliated fracture, is fusible at nearly the same temperature with lead, soluble with ease in nitric acid, and precipitable from it in the form of a white oxyd by the addition of pure water.

§ 1. Ores of Bismuth.

Sp. 1. Native Bismuth. *Gediegen Wismuth*.

The colour of this mineral is silver-white, with a slight tinge of red, frequently exhibiting an iridescent appearance on its surface. It occurs very rarely in mass, being generally disseminated, or investing; it is also met with feather-shaped, or reticular, or in lamellæ of a rectangular or triangular shape, either solitary, or heaped upon each other. It exhibits a metallic lustre of considerable brilliancy. Its fracture is perfectly foliated, or broad striated. It is semiductile, and breaks with some difficulty into irregular, somewhat blunt-edged fragments. Sp. grav. according to Kirwan = 9.57.

Native Bismuth is fusible at a very moderate temperature, often by the heat of a common candle; when exposed to the action of the blowpipe on charcoal, it volatilizes in the form of a white vapour, not unfrequently accompanied with an arsenical smell. It dissolves very easily, and with effervescence, in cold nitric acid; and is precipitable in the form of a white powder, on the addition of pure water.

The only two substances, with which native bismuth is liable to be confounded, are the sulphuret of bismuth and dendritical silver; the former of these, however, is not soluble with effervescence in cold nitric acid; and the latter may be distinguished by its colour and ductility.

Bismuth is one of the most partially diffused metals hitherto known; and it is chiefly found native, accompanied with kupsfernicksel, white and grey cobalt, black blende, native silver, and rarely galena. Its gangue is quartz, calcareous spar, or baroselenite; and it has hitherto been found only in veins in primitive mountains.

It is found at Joachimsthal, in Bohemia; at Freyberg, Annaberg, &c. in Saxony; in Sweden, Transylvania, and Britany.

Sp. 2. Sulphuretted Bismuth. *Wismuth glanz*, Emmerling. *Bismuth sulphuré*, Haüy.

The colour of this substance is between lead-grey and tin-white; but on the surface it is usually yellowish or iridescent. It is found either lamellar and in mass, or disseminated, or in small acicular crystals. Its primitive figure, according to Haüy, is that of a quadrangular prism. Its internal lustre is metallic and very brilliant; its fracture is broad or narrow striated, or foliated like galena. Sp. gr. according to Kirwan, = 6.131. It stains the fingers in a slight degree; and when reduced to powder, is of a glistering black.

When exposed to the blowpipe, it melts easily, giving out a sulphureous odour and a blue flame, and is almost en-

tirely volatilized before it can be brought to the metallic state. There has been no very accurate analysis made of this ore; but from the experiments of Sage and La Peyrouse it appears to contain about 60 per cent. of bismuth, 36 of sulphur, and a little iron. There is some external resemblance between the lamellar variety of this mineral and galena; but the superior fusibility of the former is an easy and infallible characteristic.

Sulphuret of bismuth is very rare; and, where it occurs, is always accompanying native bismuth. It is found at Joachimsthal, in Bohemia; Altenberg and Johann-Georgenstadt, in Saxony; and at Bastnas, near Riddarhytta, in Sweden.

Sp. 3. Oxyd of Bismuth, *Bismuth ochre*, Kirw. *Wismuth-ocker*, Emmerling. *bismuth oxydé*, Haüy.

This mineral is of a greenish yellow colour, passing into ash-grey, or straw-colour. It is sometimes found in mass, but more commonly disseminated or investing. It is opaque, and possesses a slight degree of internal lustre. Its fracture is fine-grained, uneven, or earthy. Sp. grav. considerable, but has not yet been accurately ascertained. It is either friable, or of the consistence of chalk, but occasionally gives fire with steel, on account of the particles of quartz, with which it is mixed.

When exposed to the action of the blowpipe on charcoal, it is very easily reducible to the metallic state. It is soluble in nitric acid without effervescence, and precipitable for the most part by the addition of water.

Oxyd of bismuth is an extremely rare mineral. It has hitherto only been found at Schneeberg, in Saxony, accompanying native bismuth; in the Black Forest mines, in Swabia; and at Joachimsthal, in Bohemia. It is often confounded with the green earthy iron ore; but may be at once distinguished by its easy reduction before the blowpipe. Emmerling, vol. ii. p. 434, &c. Wiedenmann, p. 887. Brochant, v. 2. p. 434. Haüy, v. 4. p. 184. Kirwan, vol. ii. p. 263.

§ 2. Assay and Analysis of Bismuth Ores.

Sulphur and iron are the only substances that have been as yet detected in combination with this metal, as far as can be inferred from very imperfect analyses of the preceding ores. But Klaproth, in his examination of the bismuthic silver ore from Shapbach (*Analyt. Ess.* vol. i. p. 556.), found it to be a combination of lead, silver iron, copper, and sulphur, with bismuth; and from the experiments of this able chemist is deduced the following general method of analysing the ores of bismuth.

Having reduced the ore to a tolerably fine powder, pour upon it, in a capacious flask, five times its weight of nitric acid previously diluted with one third of water. The acid will begin to act immediately, without the assistance of heat; nitrous gas will be disengaged in great quantity; and the solution will assume a greenish yellow colour. When the acid has taken up as much as it can, or nearly so, pour it off, and digest the undissolved residue in a moderate heat, with equal parts of nitric acid and water, renewing the

menstruum from time to time, till all the soluble parts of the ore are taken up. Add together the solutions, and reduce them by gentle evaporation to about half their bulk (if any crystals are deposited, add a little pure warm water just sufficient to take them up again); then pour the whole into a large quantity of rain water, at least twenty times the bulk of the solution. The liquor will immediately assume a milky appearance, and, by standing a short time, will deposit a white heavy precipitate (*a*), which, when carefully lixiviated, is *pure oxyd of bismuth*. Add all the liquors together, and concentrate them by evaporation to one half of their bulk; then drop in a strong solution of muriated ammonia, as long as any precipitate takes place; decant the supernatant fluid as accurately as possible, and, without washing the precipitate, digest it for some time with moderately strong nitric acid; the undissolved part of the precipitate being separated, washed, and dried, is *pure muriat of silver* (*b*). The nitrous solution is now to be diluted with a large quantity of cold water, and a precipitate of oxyd of bismuth (*c*) will be thrown down. The diluted nitrous solution being mixed with the other liquor, the whole must be evaporated, till a considerable number of crystals are deposited; at this time, the addition of sulphuric acid will occasion a white deposit of *sulphat of lead* (*d*). The remainder of the solution is now to be supersaturated with caustic liquid ammonia, by which the *iron* will be deposited in the state of brown oxyd (*e*), and the copper will form with the ammonia a blue solution; this being saturated slightly to excess with sulphuric acid, will deposit the *copper* (*f*) upon a piece of clean iron. The residue of the ore that was undissolved by nitric acid, being weighed, and exposed to a low red heat, will give out its *sulphur* (*g*), the quantity of which may be estimated with considerable accuracy by the loss of weight. It is now finally to be digested with ten times its weight of boiling muriatic acid, by which some oxyd of lead will be taken up; and this, by evaporation and the addition of sulphuric acid, may be procured in the state of sulphated lead (*h*). The residue being washed and dried is the stony gangue of the ore (*i*).

Hence the ore will be decomposed into

- Oxyd of bismuth (*a*) and (*c*),
- Muriated silver (*b*),
- Sulphated lead (*d*) and (*h*),
- Oxyd of iron (*e*),
- Metallic copper (*f*),
- Sulphur (*g*),
- Stony matrix (*i*)

§ 3. Reduction of Bismuth ores.

The separation of this metal from the substances with which it is found united in the mine, and the reduction of it to a marketable state, is perhaps the easiest of all the metallurgical processes, on account of the ready fusibility of bismuth, and its being found for the most part in the metallic state. The following were the methods practised in the time of Agricola (De Re Metallica, p. 349.) A round pit, two or three feet wide, was lined with well rammed clay and charcoal, and covered with billet wood, upon which were laid alternate strata of ore and wood. When the pile was thus built to a sufficient height, fire was applied to the top, and the bismuth, as the heat penetrated through the mass, became melted, and trickled down into the hole beneath, where it collected in an irregular mass; being then withdrawn, and broken into pieces, it was remelted in iron or earthen pots, separated from the impurities that floated on its surface, and finally cast into flat cakes, or loaves, for sale. Another method was to divide a large pine tree longitudinally, and cut out the central part of the wood, thus

forming it into a gutter; this being placed somewhat inclined, the ore was laid in the upper end, on a bed of chips and small wood, sufficient, when set on fire, to liquify the bismuth, which, flowing down, was collected in a hole or vessel placed at the end of the trough.

The scarcity of wood has, however, put an end to these rude and extravagant methods; and the ores of bismuth are now reduced in a common reverberatory furnace, the bed of which is lined with charcoal, whence the melted metal is removed in iron ladles, and cast into masses weighing twenty or thirty pounds, in which state it is brought to market.

§ 4. External Characters and Physical Properties.

Bismuth is a white metal with a reddish yellow tinge; is considerably hard, but brittle, exhibiting a broad foliated fracture; has a bright, almost specular metallic lustre; and is somewhat sonorous, when struck. Though brittle, it may be compressed very considerably by judicious hammering, and therefore varies greatly in its specific gravity. According to Muschenbroeck, its sp. gr. when fresh melted, is = 8.716; but when laminated, is = 9.638. Bergman fixes its gravity at 9.67; and other authors make it as high as 9.8, or even 10. The laminae, of which this metal is composed, have but little adhesion to each other; hence the primitive form of its crystals, which is that of a regular octahedron, may very easily be ascertained by dissection. It is fusible at 460° Fahr., and may be poured into a paper cone without burning it. If, after it has begun to solidify, the fluid part is poured off, a groupe of crystals is obtained in cubes, or rectangular volutes. When exposed in close vessels to a violent heat, it sublimes and attaches itself to the cooler part of the apparatus in the form of brilliant plates.

§ 5. Oxyds of Bismuth.

The combined action of air and moisture upon bismuth, at the usual temperature, is very slight; it becomes covered with a reddish grey superficial tarnish, and afterwards appears to undergo no further change. At a melting heat, it shortly becomes covered with an iridescent film, and by exposing fresh substances to the air, is wholly converted into a yellowish brown oxyd, weighing about $\frac{1}{2}$ more than the original metal. This oxyd melts into a yellow glass at a moderate red heat, and soon penetrates through the most compact earthen crucibles, though not quite so easily as glass of lead does. When bismuth is exposed to a strong heat, with free access of air, it burns with a faint blue flame, and throws up at the same time a copious white oxyd, which was formerly called *flowers of bismuth*; towards the end of the process the oxyd acquires somewhat of a yellowish tinge, probably on account of a small portion of sulphur, or other impurities. The glass, or vitreous oxyd of bismuth, is a very active flux for earths and the more difficultly fusible oxyds; on account, however, of the superior cheapness and efficacy of lead, it is seldom used for this purpose.

§ 6. Action of Acids on Bismuth.

1. Concentrated sulphuric acid has no action on bismuth, except when boiling hot; in this state, it is rapidly decomposed, giving out sulphureous acid gas, and reducing the metal to a white pulverulent oxyd; by a low red heat the decomposition is so complete, that a quantity of actual sulphur is volatilized. The white mass being washed with a little warm water, parts with nearly the whole of its acid, holding a small portion of bismuth in solution: this fluid, by careful evaporation, deposits minute soft crystalline needles of sulphat of bismuth, from which, by the mere affusion of water, the metal may be separated in the form of white oxyd. The sulphated oxyd, produced in the first

part of the process, is remarkably more difficult of reduction than any of the pure oxyds of § 5.

2. Sulphureous acid is incapable of attacking metallic bismuth, but readily combines with its oxyd, forming a white insoluble sulphite of a sulphureous flavour, reducible into metallic globules before the blowpipe, decomposable with effervescence by sulphuric acid, and when distilled, giving out its acid, a mass of pure white oxyd remaining behind.

3. Nitric acid acts upon bismuth in a remarkably violent manner. If the metal is in powder, and the acid somewhat concentrated, at the instant of their mixture, even without the assistance of heat, a rapid decomposition of the acid takes place, accompanied with the production of nitrous gas, azot, and sometimes of ammonia; and the bismuth is converted into a white oxyd. If the acid is previously diluted with an equal weight of water, and the bismuth is added gradually in small pieces, the decomposition goes on more quietly, the metal is dissolved in proportion as it oxydates, and the acid may be made to take up nearly half its weight of bismuth. By cautiously adding to this solution an equal bulk of distilled water (each portion being well mixed with the whole mass by stirring, before the addition of a succeeding portion), a black pulverulent precipitate takes place, which has not yet been analysed, but has been taken for sulphur or charcoal. If the acid made use of is still more dilute, consisting, for example, of four parts of water, and one of nitric acid, the black matter is not dissolved. Nitrat of bismuth, when thus purified, is clear and colourless, and by gentle evaporation crystallizes in the form of flattened rhomboids, or compressed tetrahedral prisms terminated by three sided pyramids. This salt, when exposed to a dry air, is considerably efflorescent; but in a humid air, becomes covered with a white, somewhat moist coating of oxyd. When thrown on hot coals, it detonates feebly, giving out faint red sparks, and leaves behind a greenish yellow oxyd of difficult reduction. If a crystal of nitrated bismuth is thrown into some pure water, it immediately becomes covered with a white opaque oxyd; but the decomposition of this salt is more striking, if a solution of it is made use of. For this purpose, let a jar be nearly filled with clear rain water, and drop into it nitrat of bismuth as long as any precipitation takes place, then mix the whole by agitation, and let it stand for an hour to settle. The bottom of the vessel will now be covered with a fine heavy powder of a dazzling white, which, when repeatedly washed and dried, is pure oxyd of bismuth, formerly called *magistery of bismuth*, and well known as a cosmetic under the name of *blanc de fard*. This preparation, if made with pure nitric acid, and well washed, is of a dead white; but if a little muriatic acid is mixed with the nitric, and the precipitate is washed with a small portion of cold water, it will be in the form of minute glittering scales with a beautiful pearly lustre, and is then called by the French *blanc de perle*. In both states it is extensively employed, particularly by the French ladies for whitening the skin, but is subject to turn grey, brown, and even black, by any hydrogenous and sulphureous vapours. This oxyd of bismuth does not appear to retain any nitric acid; and its component parts are fixed by Bergman at 77 of metal, and 23 of oxygen; but, by the more accurate experiments of Klaproth, its contents are ascertained to be 81 of metal to 19 of oxygen. Nitrated bismuth is not, however, totally decomposable by water; for the clear fluid, that is separated by filtration from the oxyd, may still be made to yield a precipitate by a carbonated alkali, muriatic acid, or muriated ammonia. Klaproth found (Analyt. Ess. vol. i. p. 557.), that 100 grains of bis-

muth, dissolved in nitric acid, yielded with water 88 grains of oxyd, and 35 more were obtained from the diluted solution, by the action of muriatic acid added in drops as long as any precipitate ensued. This oxyd is very easily reduced by fusion in a covered crucible, with a little nitre and tartar.

4. Bismuth in the metallic state is acted upon with difficulty by muriatic acid, even when it is concentrated and assisted by heat. During the digestion, a small quantity of fetid hydrogen gas is given out; and, by slow evaporation, small deliquescent needle-shaped crystals are deposited of muriat of bismuth. This salt, however, may be obtained in much greater quantity, and more easily, by substituting the oxyd of bismuth for the pure metal. If the saline mass, which remains behind after evaporation to dryness, is distilled in a glass retort, nearly the whole of it comes over at a moderate heat, and concretes into a soft white mass, called formerly *butter of bismuth*. Butter of bismuth, like butter of antimony, is intensely caustic to the taste, deliquesces in a moist air, and when dropped into water, is decomposed, a fine white oxyd being precipitated.

5. Liquid oxy-muriatic acid acts upon metallic bismuth with considerably more energy than muriatic acid does: the metal is oxydated without the disengagement of hydrogen, and the result is muriat of bismuth. It is probable, that by substituting the oxyd of bismuth for the pure metal, oxymuriat of bismuth might be produced: this, however, is not as yet confirmed by experiment. If bismuth, previously reduced to fine powder, is poured into oxymuriatic acid gas, the metal is instantly ignited and oxydated, and falls in a shower of fire to the bottom of the vessel.

6. Tincture of galls, or gallic acid, precipitates bismuth of a greenish colour from its solution, as prussiated potash does of a yellowish colour.

7. There is scarcely any thing known concerning the other bismuthic salts. They are formed by digesting the yellow oxyd in the various acids that have not been already mentioned, and are for the most part but little soluble in water. The proportions of their ingredients have not been ascertained with any accuracy, nor are they applied to any use.

§ 7. Action of the Alkalies and Earths on Bismuth.

The fixed alkalies have no effect on metallic bismuth, but unite both in the humid and dry way with its oxyd. Ammonia is said to acquire a greenish yellow colour by digestion with the metal when pulverized, and certainly dissolves its oxyd in considerable proportion. The action of the earths upon bismuth is unknown, except that silex and oxyd of bismuth combine by fusion into a clear greenish yellow glass.

§ 8. Action of the Neutral Salts on Bismuth.

None of the neutral salts in solution appear to exert any affinity on bismuth or its oxyds; but, in a dry heat, many of them are decomposed by it.

Nitre, being mixed with pulverized bismuth, and projected into a red hot crucible, is decomposed with a slight detonation; the bismuth becomes oxydated, and then unites in part with the alkali base of the nitre.

Muriat of soda, according to Pott, is in some degree decomposable by metallic bismuth. This fact, however, is not confirmed by later chemists; and it is probable, that the salt, which Pott made use of, was not free from muriated magnesia, and that the bismuth was partly oxydated.

Muriated ammonia is totally decomposable by oxyd of bismuth. On the first impression of the fire, very pure ammoniacal gas is disengaged; and by a low red heat, the muriated bismuth rises in the form of a thick white vapour, which concretes, in the receiver and neck of the retort, into *butter of bismuth*; if the oxyd of bismuth is in very small

proportion to the muriat of ammonia, the greater part of this salt rises entire, but mixed with a little muriat of bismuth, forming the *bismuthic flowers of sal-ammoniac* of the old chemists. When these flowers are thrown into water, the bismuth is deposited in the form of a white oxyd.

Oxymuriat of potash mingled with powdered bismuth, and projected into a hot crucible, is decomposed with great violence, and the metal is completely oxydated. A mixture of three parts of this salt, and one of bismuth, produces a flash and a loud detonation, if laid on an anvil and struck smartly with a hammer.

§ 9. *Bismuth with combustible Bodies.*

If one part of sulphur, and four of bismuth, are triturated together, and afterwards exposed to a full red heat in a covered crucible, a brilliant striated metallic mass of sulphuret of bismuth is obtained, similar in its properties to the native sulphuret mentioned in § 1. It may be made to crystallize, by allowing it to cool very gradually, and pouring off the fluid part as soon as the surface is crusted over. The cavity thus formed will be found to be lined with long tetrahedral prisms crossing each other, and occasionally of a deep iridescent blue and red colour, forming groupes of exquisite beauty. The sulphuret of bismuth is much less fusible than the pure metal; it parts with nearly the whole of its sulphur by long roasting, and is decomposable by nitric acid, which dissolves the bismuth without touching the sulphur.

Sulphuretted hydrogen converts the white oxyd of bismuth into a black mass, of which neither the properties nor proportions have been ascertained.

Phosphorus has very little affinity for this metal. Pelletier tried in vain by several methods to prepare phosphuret of bismuth. In some of his experiments, the metallic globule, when red hot, gave out a faint lambent flame, but exhibited no other proof of combination with phosphorus. Fat oils, by the assistance of heat, dissolve the oxyd of bismuth, and form with it a thick tenacious plaister.

§ 10. *Alloys of Bismuth.*

Bismuth appears to increase remarkably the fusibility of all the metallic compounds into which it enters; but it is to

be lamented, that we are greatly in want of accurate experiments on this interesting branch of inquiry.

1. *Bismuth and Gold.* See GOLD.

2. *Bismuth and Silver.* See SILVER.

3. *Bismuth and Iron.* See IRON.

4. *Bismuth and Copper.* See COPPER.

5. *Bismuth and lead.* Equal parts of these two metals unite easily by simple fusion, forming an alloy of a brilliant white colour, considerably harder than lead, and, though not ductile, more malleable than pure bismuth. By diminishing the proportion of bismuth, the malleability of the mass is increased, without sensibly impairing its fusibility, hardness, and lustre.

6. *Bismuth and tin.* A small quantity of bismuth increases the hardness and brilliancy of tin, without rendering it less ductile; hence the best foils for glass mirrors are made of this alloy, as also are some kinds of pewter.

Bismuth with lead and tin. Fusible metal. Plumbers' solder. The fusibility of the alloys of bismuth is in no instance so remarkable as in that discovered by Newton, and thence commonly called Newton's fusible metal. It is made by melting together eight parts of bismuth, five of lead, and three of tin. The mass is very brittle, and when broken exhibits a porcellaneous appearance, with little or no lustre; it is so fusible as to become liquid when held on a piece of stiff paper over a candle, without scorching the paper; and becomes as fluid as quicksilver in boiling water. If the bismuth is reduced to one part, the proportions of lead and tin remaining the same, the alloy is plumbers' solder; and it differs from the preceding in being somewhat less fusible and considerably malleable.

7. *Bismuth and Mercury.* See MERCURY.

8. *Bismuth and Iron.* See IRON.

§ 11. *Medical Use of Bismuth.*

The magistery, or white oxyd, is the only form of bismuth which is employed medicinally. It is prescribed with success in spasmodic affections of the stomach. Gren. Syst. Handbuch, v. iii. p. 292. Leonhardi's Macquer. art. Wismuth. Fourcroy Syst. des Connaiss. Chimiques, vol. v. Beaumé Chem. experimentale, vol. ii.

Bits

BITS, or **BITTS** for *Horses*, in the *Manege*, are pieces of iron of various figure and construction which, being placed in the horse's mouth, serve, by the assistance of the reins, to restrain or guide his motions.

The term *bitts*, or *bits*, is considered by some as originating from the horse's biting or champing them between the teeth when placed in his mouth; in the French language is used a term also of similar signification, *les mors*, which would seem to corroborate the above etymology of it:—another however, equally natural, presents itself in the common word *bit*, or *bitts*, that is *pieces* of iron; this apparatus being always made of one or more pieces of this metal.

The art of biting horses may be said to consist in furnishing the mouth with the most proper mouth-pieces, &c. for obtaining from them an obedience to the will of the rider, and exacting a due performance of all the movements and restraints which may be desired, or at least which are dependent upon the operation of the reins. Rightly understood, and well administered, this art affords the power of communicating to the horse support and confidence, with greater ease and security to the rider. The misapplication of its rules, on the contrary, or an inattention to them, where the mouth is not totally insensible, will produce painful sensations to the horse, with disgust and rebellion, and to the rider uneasiness and perhaps danger.

It is to be lamented that the presumptuous opinions of the uninformed have been too much the guide of the public in their estimation and choice of the proper bits for horses, as also in too many other things respecting these useful animals, tending often to accumulate unnecessary suffering and misery upon them. The writers on this subject are few and unsatisfactory; we shall, however, except Mr. Berenger, whose work is a noble effort to emancipate this branch of science from barbarity and ignorance; and from him we shall take occasion to make some extracts in the sequel of this article. Here it will be proper to observe, that this author, by the term *bit*, has designated the curbed bit only, but we have ventured, for the sake of pursuing a more connected view of the subject, to include in this term any piece or pieces of metal placed in the horse's mouth, for the purposes of guidance or restraint.

In our account of the different kinds of bits, and their effects, we shall begin, for the sake of order, with the description of a bit of the most easy and simple construction possible, and then proceed to the most complicated.

A short iron rod, made rather wider than the mouth of the horse, and provided with a hook or ring at each extremity for fastening the reins to, affords us an instance perhaps of the greatest possible simplicity in the construction of

a bit; and such a one only slightly curved forwards, to allow more liberty for the tongue, is at present in general use for the heavier kind of draft horses, the bearing rein being usually attached to it, passing over the hames of the collar.

A similar rod to the former, broken in two pieces, and connected by a joint in the middle, is the next in point of simplicity, and is in common use for horses of light draft; as in those employed for the currie, coach, &c. and is attached by the bearing rein to the hook of the saddle, and this kind of bit is mostly termed with us a *bridon*.

The next in point of farther complication of parts, and which scarcely can be said to differ from the former, is the *common snaffle*. This is provided with two cross pieces, which rest against the lips or sides of the mouth; for as the snaffle is intended for the saddle horse, and the reins go to the hands, so the cross pieces are useful in preventing the bits from being drawn through the mouth, which precaution is not so necessary where the bits are affixed to the bearing rein. The *bridon* we may observe, is also made in general smaller than the snaffle, as well as without cross pieces.

The distinction, however, between a *bridon* and *snaffle* is insignificant and of little consequence; for on all occasions cross pieces are the most convenient; and it will be easily seen that the *bridon* is merely an imperfect snaffle, possessing no peculiar characters which can form a real distinction.

The term, also, when confined to this object is misapplied; for the French, from whom we have borrowed it, by *le bridon* understand the snaffle and its rein, in opposition to *le bride*, by which they denote the *curbed bit* and reins.

In war, and on other occasions, the *bridon* was used as a lesser bridle, or bridle of reserve, in case of the failure of the former from any accident; and hence the origin of its name.

The number of parts of which the mouth-piece of the snaffle is composed, may be increased to any extent, as it may be made with one, two, or several joints; but as it is evident these additions will not essentially alter its properties or effects, it would be useless to pursue a distinct consideration of them.

But the condition of the snaffle admits of being so altered and changed by the variation of its figure, its substance, and its surface, as to acquire new properties and effects which will require particular attention; its gentleness or rigour will depend almost wholly on these conditions. A mouth-piece made of two entirely straight pieces will be more severe than when these are somewhat curved, as the curved bit is more apt to embrace and include the lips between it and the bars than the

the straight one. A thin and slender bit or snaffle, it will be easily perceived, will rest with more severity and sharpness upon the bars than a thick and obtuse one; the former, therefore, or the sharp bit, is employed more particularly for restraining such horses as are hard mouthed, and too eager, while the latter is used for such as have a proper feeling of the bars, and especially for breaking in young colts.

The surface may be varied as to roughness or smoothness, producing also different effects. To give the greatest ease possible, a large and highly polished bit is necessary. This is sometimes provided with moveable rollers on the axis of the bit, which, turning with every movement of the reins, diminish the friction of the bits, and render them less irritating. These rollers, however, in reality can have but little effect in the snaffle, though of pleasant effect in the mouth piece of the curb; for this reason, that the snaffle being jointed in the middle, is drawn by the reins to a sharp angle in the mouth, so that these rollers are presented to the bars in an oblique direction, under which position it will be obvious they can have very little or no motion, but, on the contrary, they will tend to render the bits more severe by their irregularity; so that a well polished snaffle is in fact preferable to one of these with rollers of the ordinary construction.

On the other hand, to give the greatest degree of severity to the mouth piece of the snaffle, it is twisted while hot into a spiral form, and is made to present by this means a sharp, rough, and unequal surface to the jaw, being capable, according to the degree of sharpness to which the edges are wrought, of punishing the bars and lips with greater or less severity. The different degrees of punishment which this kind of bit is capable of inflicting, will perhaps be found sufficient for all the purposes of correction, where recourse may properly be had to actual force and punishment. For it should be always kept in view, that gentle means will produce a good mouth; while harshness and too great severity will tend to destroy it altogether.

Thus far the ancients of the most remote ages of the world, almost as far back as any history extends, were well acquainted with the use of bits. Xenophon, more than 400 years before Christ, had described similar bits as being in common use in his time among the Grecian states. He speaks of a smooth and a sharp kind of bit, the latter, if more severity was requisite, to be armed with points or teeth. In its use, however, he enjoins the greatest tenderness, and observes, "that when you would wish to slacken the pace of an eager horse, which hurries on too fast, and to pacify his fury, so as to make him go more temperately, or even oblige him to stop, you should not attempt to do it at once, and with violence, but artfully, and by degrees, gently pulling him in, then yielding the bridle, and playing with his mouth, in such a manner as if you intended rather to win his consent than force his obedience." Chap. 9, 10.

Beyond the changes above described, the snaffle itself does not appear to admit of any alterations worthy of notice. It may, however, be just observed, that some horsemen add a chain to it, extending from cheek to cheek, which resting loosely on the tongue produces irritation and flavering, and, as they imagine, freshens the mouth. Such a bit is known by the name of the *Rockingham snaffle*.

The reins, however, it must be remarked, admit of some alterations in their disposition, which will influence the effects of the bit on the mouth; as whether they are carried higher or lower. At this present time there is a practice more especially in horses of light draft, as in those for carriages, carriages, and chairs, &c. to distort and alter the bearing

reins from their natural direction, and to dispose them more perpendicularly and in a line with the head; so that instead of passing straight from the mouth to the horse's back, they are directed up the sides of the face, as high nearly as the parotid gland, or base of the ear, where they are passed through a ring hanging from the head stall, and from thence to the hook of the saddle. The appearance is ornamental and elegant, and the reins so disposed are considered as more forcibly elevating the head than if they proceeded to the back in the usual direction.

As the disposition of the reins, so the figure of the bits themselves, and the ornamental appendages attached to them, admit of almost endless variety. The manufacturers of these articles, availing themselves of this licence, render their business more lucrative by as frequent changes as possible. These are successively introduced as fashionable novelties, till again for novelty they return to the simplest practice; and this takes place without any alteration in the principal circumstances of their construction, properties, or use.

The next kind of bits in use for horses is the curbed bit; which, as it is an instrument of much greater complication of parts than the snaffle, so it appears to have been of comparatively recent date.

In some of the sculptured equestrian figures of the ancients something like the branches of the curb may be found; but in no instance does there appear any thing resembling the chain, which is absolutely necessary to its effect. Their writings also appear to be silent on this subject. It was probably the invention of Italy or France, which for some centuries past have taken the lead of the other nations of Europe in teaching the arts of the manege. It was first introduced into the English army by a proclamation made in the third year of king Charles I. since which time it has got into universal use for the army, the field, and the road, so that no horseman deems himself perfectly equipped without it. Most of those writers who have treated of it in the last, and in the century preceding that, and who wrote probably soon after the commencement of its use, have been very profuse in their various proposals for the structure of it, especially in rendering it more complicated, severe, and cruel; though it is probable their clumsy figures and representations were never imitated in actual practice. They appear to have been much satisfied with their new invention, imagining it a sure means of reducing horses to immediate obedience, in spite of every obstacle; and true it is, it can punish with extreme severity: but is such a measure most likely to create vice, or to overcome it? Indeed, according to the opinion of one of the ablest writers that has ever considered this subject, and whose opinion we shall take an opportunity of quoting more fully hereafter, little or nothing has been really gained by its adoption; on the contrary, the snaffle possesses more simplicity, power, and perfection.

Stripped of all unnecessary trappings, this instrument consists of the following essential parts: a mouth-piece with two side branches, or inflexible rods of iron, firmly fixed to the former, and a chain passing from side to side, behind the chin, including the jaw; two eyes or rings at the upper extremity of these branches, serve to fasten it to the head-stall, and to stay it in the mouth; two other rings at the lower extremity of the above branches receive the reins, passing to the hand, or sometimes in draft horses to the hook of the saddle, as a bearing rein. These are all the parts really necessary to constitute the curb.

The bits thus formed being placed in the mouth, and the chain passed round the lower jaw, the branches, it will be

readily seen, become powerful levers when drawn backwards, acting upon the mouth-piece as a centre, and squeezing, by means of the chain, whatever interposes between it and the mouth-piece, with a force equal to the length of lever afforded by the lower branch.

This force, it will be perceived, is influenced and regulated not only by the length of the lever below the mouth-piece, but also by the greater or lesser distance at which the chain is placed from it. The chain is usually fixed to the eye of the cheek-piece, where the head-stall is fastened; if, therefore, this part is very long, it is evident it must moderate or counteract the power and effect of the lower end of the branch, and render it less severe by bringing the centre of motion nearer to the middle of the lever.

It appears manifest, from the construction of this instrument, that its whole force is exerted upon the jaw itself, and that it has power to pinch the bars with cruel violence, even to the fracture of the bone, and this with very powerful branches has sometimes happened. It can also crush and bruise, and totally destroy the tender covering of the inside of the mouth, and the skin beneath the jaw.

From considering its mode of operating, it might reasonably be doubted whether it does in reality stop the horse by its power and opposed force, as is generally conceived at present, or rather by the severity of the pain it inflicts; as should the horse arm himself against this, it is totally insufficient to arrest his course; of which instances occur in runaway horses every day. And we shall venture to suggest, though contrary to the general opinion, that the snaffle, even in this respect, if the mouth has not been previously hardened and spoiled by the use of the curb, is the most powerful instrument of the two.

The *mouth-piece* of the curb is usually provided with an upset or arch in the middle of it, as it would, if perfectly straight, rest on the tongue, and occasion an unpleasant restraint. This passage for the tongue is often made so narrow and small by the bit makers, that one should apprehend they scarcely had a right idea of its use. From the circumstance of its allowing a passage for the tongue, it has been called by some, the *liberty*; and, for the same reason, by others, the *porte*: hence we have the *porte-mouth* bit, vulgarly called among the bit makers and grooms the *Portsmouth* bit: and by a supposed counter expression to this term, we probably get the *Weymouth*-bit.

In draft horses, especially for the coach, it is a frequent custom to have affixed to the upper part of the upset small chains or polished drops of iron, which hanging loose in the mouth, and falling on the tongue, occasion the horse to champ the bits, and create a copious flow of saliva, so as to slobber the lips with its white froth; and when this happens, it is considered by some a good sign of health and gaiety, and that the horse is well bitted; for, if the bits are disagreeable to him, he never plays with them, or exhibits any froth, say they. These small appendages are termed by the French *les chainettes*, and by the English *players*.

It is farther to be observed, respecting the mouth-piece of the curb, that the straight part which rests upon the bars of the jaw, is termed by the French *le canon*, and by the old English writers the *jeive*; and though a highly convenient and useful word, it is to be regretted it is at present out of use; the French term, which is not so expressive, having superseded it. This part should be well polished, and may be made of any proper figure, as that of a cylinder, cone, oval, globular, pear-shaped, &c.

It is obvious that the effect of the curb, as far as it re-

spects the bars, will be correspondent to the thickness or thinness, smoothness or roughness, of this part; the larger and broader it is, the more surface it covers; and thus the pressure, by being distributed over more points, becomes less felt. This enlargement, however, of the canon or jeive should not be carried to an excess, by making it too heavy, or filling the horse's mouth with more iron than it can conveniently receive, and thus create pain, instead of greater ease.

To render these irons less irritating to the mouth, and to avoid their friction upon the bars, the jeives are provided with loose, moveable rollers of well polished iron, which readily turning on the axis of the bits, very considerably diminish their severity. These moveable pieces are also particularly useful in preventing the horse from catching and holding the bit in his teeth; as the curb, under these circumstances, can still move and act with the same freedom as before.

The jeives are sometimes composed of three or four flat-tish knobs, united by a joint to each other, and with a joint to the upset, which is intended to render it very severe; it is obvious, however, that such an alteration must bring it nearer to the condition of the snaffle; the knobs, however, if they can be drawn transversely across the bars, might produce considerable irritation, but not so much as they would do if not jointed. This bit is not unfrequently used, and is called with us the *Hessian*-bit.

To the curb is often fixed a ring opposite the mouth-piece, which, as it is directly in a line with the axis of the bit, has no other effect when the reins are affixed to it, than a snaffle would have provided with a similar mouth-piece. This is termed putting "the reins to the cheek," and for horses of light draft, whose mouths are not ruined, it is by much the best, as the mouth is less annoyed, and the horse obeys with more alacrity the guidance of the hand from this point, than from the extremity of the branches, which are particularly ill calculated for this purpose: this kind of construction is generally distinguished by the name of the *Peckham* bit.

In the older English writers, as well as those on the continent, on the subject of bits, we find an appendage described, which is not at all, at present, in use; and as it enters the mouth with the mouth-piece, it may, with propriety, be described along with it. It consisted of a chain extending from branch to branch of the banquet, or cheek piece, being placed rather above the mouth-piece, and parallel to it, and was stretched across perfectly straight and tight. This part was called the *water-chain*, and by the French *Trenche-file*: its use is not very evident. Mr. Berenger takes notice of it, and observes "that it might be useful to horses that are apt to drink or swallow the bits, as the expression is, or bury it so deep in their mouths, as to hinder it from having a due and just effect;" from its being laid aside so generally, we presume it has at least been thought useless.

It is a common belief with the grooms, that a great power resides in the upset of the mouth-piece, and that the bits are more powerful as this is longer or shorter; nothing, however, can be more fallacious than this reasoning. In the works of Laurence Reece, also a French writer, we find, in consonance with this idea, a curb, with an upset of unusual length, being destined to correct the vices "*d'un Roussin qui à la bouche d'une diable*;" it will be obvious, however, on a moment's reflection, that this part, from being made very lofty, and coming forcibly against the palate, would compel the horse to open his mouth, when it would cease farther to act in any way; with more reason, the same writer proposes, on the other hand, "*pour donner*

grand plaisir," to have a bit constructed with a low upset, and sufficiently wide, with large, conical, smooth jeives for the bars.

Of the chain. The chain is the part most essentially necessary to give effect to all the other parts of the curb, and may be placed, as we have already noticed, at any given distance above the mouth-piece; its operation being more powerful, as this distance is exceeded by the length of the branches. This position, though true as a general principle of reasoning, appears to be subject to the operation of other causes in actual practice, which it will be necessary to consider; for, in direct contradiction to this is the assertion of Mr. Berenger, who appears to be almost the only writer who has truly investigated the merits of this particular object. He observes, in regard to this, that the nearer the chain, and the longer the branches, the softer and more indulgent its operation. This, on a first view, would appear to be in direct variance with the rules above laid down, and irreconcilable to the well known laws of the operation of the lever, and even at variance with his own preceding assertions; when, however, we remember the experience and practical knowledge of him who asserts it, it deserves a more particular consideration; let us first admit the truth of the position, as it seems founded on the sure test of actual experience, and then we should venture the following as the most natural explanation of it.

In proportion as the branches are longer, the more extensive is the circuit their extremities perform in their operation; and therefore, the hand that guides them must pass through a greater space to produce the same effect: and now, if the chain be placed very near to, or upon the outside of the mouth-piece, and be applied not very tight about the chin, yet, in reality, though there would be an apparent increase of power by the length of the branches, they would have little or no effect, as they would arrive at the utmost extent to which they can be drawn, before the chain would begin to pinch. On this account, the most lively effects would be produced by the chain having more sweep and extent of action, and by the branches being not quite so long, as great length also adds something to their flexibility, though not to a degree to be worth taking into the account. Still, however, the branches must ever obey the common laws of the lever, acting with force proportioned to their length; while shorter branches act with greater quickness, and are more lively in their impression.

The chain is fastened on one side to the eye of the banquet, where the head-stall is fastened; on the other, to a hook hanging from the same part. This chain, as it is at present used, is composed of iron links or rings, so bent or indented, as to form, when put together, one uniform nearly flat surface; and these links, by twisting or untwisting, may be made to present a surface with any degree of roughness to the chin.

When great tenderness is required, this chain may be covered with leather or cloth; or where a still greater delicacy is desirable, the curb may be made wholly of leather, without any chain.

The larger and thicker the rings are, provided they are smooth and well polished, the easier the effect of the chain. In old English, this chain was called the *kirble*; and hence, by contraction, *kirb*; and finally, by an easy transition of the *ki* into *cu*, we apprehend that the modern appellation of this instrument is obtained.

Of the branches. The proportion which the cheek part bears to the lower extremity of the branches, or rather the position of the eye, to which the chain is fixed, determines the degree of power of the bit upon the principle before advanced;

that is, if the chain is fixed to the upper extremity of it, as it usually is to the transverse opening or eye of the head-stall.

For the elementary view we are taking of the construction of the bits, it has been only considered as a straight, plain lever of indeterminate length; it is, however, in practice, often varied, as in the army, it is used of enormous length, and frequently curved like the letter S, by which it is conceived to be rendered more powerful, as well as ornamental; at other times the branch of the bit, with a view of increasing its force, is carried forward with a sharp elbow, giving nearly the figure of the letter Z; while by others, with more reason, to prevent the horse from catching the bit in his mouth, it is made with an arch, or semicircle, in the middle of the branch, like the letter C, turned backwards for the same purpose; still, however, in fact, whether bent into that or any other shape, it is the length of the lever, and its strength, which alone give the power; it is true, however, that a long curved branch, though more powerful, will render the effect somewhat softer, as coming from a greater distance, especially if the branch is at all flexible and yielding, than it would by the quick and rigid effect of a shorter lever, made perfectly straight and inflexible: these branches may also be turned or bent, not only backward or forward, but also outwards and inwards. At their extremities, those turned outwards, are said to be strongest of any in their operation.

As to the cheek-piece, or banquet, as it is called by the French, for an appropriate name is wanting to this part in the English language; the eye of the banquet, say the horsemen, commands and gives efficiency to the rest of the bit; or, in other words, decides the distance of the chain from the mouth-piece, or centre of motion; as, however, in speaking of the other parts, we have had occasion to introduce a sufficient account of this, it will not be necessary further to give it a separate consideration; nor will it be useful to describe the numerous mongrel herd of bits engendered of the snaffle and curb, which are reducible to the properties of one or the other, or partaking of both.

The most useful bit of the curved kind, appears to be the *Weymouth-bit*, which is at present in common use for draft horses of light work, as for carriages, coaches, &c. It consists of a strong, plain mouth-piece, of uniform thickness throughout, without any upset or jeives, but is simply curved forwards, to give liberty to the tongue: this kind of construction is the simplest perhaps that the curb admits of.

In concluding, it remains for us to notice the proper application and adjustment of these bits to the horse's mouth, and to treat of their real effects.

By the management of the head-stall, the snaffle bits should be so adjusted as to fall in the middle space between the teeth and grinders, resting upon the bars: the mouth-piece of the curb should also occupy the same situation; when, however, it is used along with the snaffle, the bits of the snaffle should be placed highest in the mouth.

If the bits are placed too high in the mouth, the horse carries his head aloft; if too low, he slops the head, and tries to catch them in his teeth.

The thicker and more fleshy, and the wider or broader the bars of the horse, the rougher may be the mouth-piece for the leaner and more delicate; consequently, the bits should be less severe. Care should also be taken that the mouth-piece be well suited to the size and width of the mouth, and be not too narrow, as this would give pain, by squeezing the bars together: if, on the contrary, it is very wide, it rests with more force on the bars, without the interposition

of the lips, as is most usually the case. Where the tongue is large and prominent, the upset should also be in proportion, otherwise the bits could not rest upon the bars, but would press upon the tongue.

In regard to biting the horse, and the consideration of its effects, we cannot desire to see any thing more consonant to truth and reason, than what has been given us by Mr. Benger, and with some useful extracts from his valuable performance, we shall conclude this article.

Of biting horses with the curb. "In the beginning of an undertaking, whose aim is to subdue and reclaim nature, and that at a time when she is wild, ignorant, and even astonished at the attempts which are made upon her, it is evident that she must not be treated but with lenity, instructed with patience, and by small degrees, and that nothing should be offered that may hurt, surprise, or occasion any disgust.

The horseman, therefore, should not act the part of a tyrant, but of a lover; not endeavour to force her to submission, but strive to gain her consent and good will by assiduity, perseverance, and the gentlest attentions; for what prospect of success would rougher manners afford? To what purpose would it be to compel a colt to go forward, or turn from fear of the whip or spur, and to trot and gallop so freely as to supple his limbs, and form his paces; if the novelty of the bit, and the unaccustomed restraint to which it subjects him, should vex and confound him, so as to make him not know what to do, or how to behave in these extremes? It cannot be expected, that he will be guided, and go with ease to himself, or pleasure to the rider, if the instrument, by which he is to be conducted, offends or gives him pain: all habits and acquirements should be attained gradually, and almost imperceptibly: rigour and precipitation would ruin all; and, instead of forming the horse to the execution of what is required, may plunge him into vice and rebellion, so as to occasion much trouble and loss of time before he can be reduced.

He should not therefore, at first, be considered as if he was designed to be formed to all the delicacy and exactness of the bit; and the horseman should be content, if he will endure it in his mouth, so as to grow, by little and little, accustomed to it, till the restraint becomes by habit so familiar and easy, that he not only is not offended, but begins even to delight in it; for this purpose, great care should be taken that the bit be easy and gentle in all its parts; that the mouth piece be larger than it need be for an horse already bitted; that it in no wise incommodes the bars, squeezes the lips, or galls the tongue.

The mouth-piece, called a cannon, with a joint in the middle, will be the most suitable; the ends of it should be as large and full as the size of the mouth will permit, for the thicker and more blunted they are, the easier they will be for the horse, and the *appui* less strict and severe.

The links of the curb should be big, smooth, and well polished; the curb somewhat long. The branches should be exactly even with a line of the banquet, to make the *appui* moderate and equal; they should likewise be long; nor does it signify of what shape they are, for with most horses they ought to be so weak, as scarcely to have any effect: so requisite it is to guard against every thing that may annoy or disturb the horse in these first trials. In order to reconcile him to this new constraint, the reins should be held in both hands; and the horse, for some time, should only walk under the rider. Above all, upon this, and all other occasions, a firm, a light, and diligent hand, is necessary.

Such are the outlines and general principles upon which

the art of biting horses is established; which art, as far as it reaches, is sure and constant; but which, in spite of all the merits and praise of which it has so long been in possession, will, upon a serious and strict trial, never, I doubt, be found adequate to the views of a sound and intelligent horseman, nor capable of bringing a horse to that degree of suppleness and exactness of carriage, which the truth and perfection of the art require, these attainments seeming to have been reserved for a more simple but powerful machine, called the *snaffle*."

"To perform his business justly and gracefully, the animal must first be made supple in his fore parts, and his head and neck so managed, that one may be raised, and the other arched or bent, more or less to the hand to which he is to turn. The bridle, called the bit, is so impotent in its endeavours to raise the head, that it even produces the opposite effect; nor from the confinement in which it keeps the horse, and the small compass it affords for the action of the rein, does it allow the rider sufficient room to bend him, without pulling down his head, and putting him upon his shoulders, both of which are incompatible with the true and sound principles of the art. The frequent use of cavecons and bridons, fully evinces the want of power in the bit to supple the horse, or raise the fore part.

The figures and representations of horses working upon different lessons, may be appealed to for the confirmation of this assertion: the books of past times abound with them, especially that boasted work of that king of horsemen, the duke of Newcastle, whose horses are all drawn with their heads between their knees; and yet are exhibited to the equestrian world as standards of truth, and models of perfection. The successors of this duke, and of other great masters, as imitators, are generally a blind and servile herd, ran headlong into the errors, and adopted the faults of their predecessors; and always made use of bits, without reflecting upon their effects, or perceiving that they could operate to make the horse carry low, or to put him upon his shoulders, while they thought that he was all the time upon his haunches."

"If ever there was a panacea, or universal medicine, the snaffle is one for the mouths of horses: it suits all, and accommodates itself to all; and either finds them good, or very speedily makes them so; and the mouth once made, will be always faithful to the hand, let it act with what agent it will. This bridle can at once subject the horse to great restraint, or indulge it in ease and freedom: it can place the head exactly as the horseman likes to have it, and work and bend the neck and shoulders to what degree he pleases. He can raise the head, by holding up his hand; by lowering it, it can be brought down; and if he chuses to fix and confine it to a certain degree he must use for this, as well as for the purpose of *bending, double reins*; that is, two on each side, the ends of which must be fastened in a staple near the pommel of the saddle, or to the girths, higher or lower, as the mouth, proportions of the horse, and his manner of going requires; and if properly measured and adjusted, they will form and command the horse so effectually, as, in a great degree, to palliate many imperfections of the mouth, and many faults in the mould and figure."

"The reins thus fastened, or even one only, for the sake of working one jaw and one side, will operate more or less, as the branches of a bit: and the snaffle will almost be a bit, a bridon, a cavecon, and martingal, in one. When the horseman would bend the horse, he must pull the rein on that side to which he is going, and lengthen that of the opposite, that they may not counteract each other. No-

thing will awaken a dull mouth, and bring it to life and feeling, so soon as this bridle. If the mouth be hard and callous, the iron should be so twisted as to have a sort of edge, which will search the lips, and when they will permit, the bars also; and if gently moved, or drawn from side to side, keep the mouth fresh and cool. If the twisted, or rough snaffle, be thought too harsh, and the hand not skilful enough to moderate its effects, a smooth snaffle may be used; or if a bit of linen be wrapt round the twisted snaffle, it will make it easy and smooth; and the mouth, once made fine and delicate, will be true to its feelings, will obey the snaffle, and follow the hand with as much exactness and precision as the bit knows to demand, but with more freedom and boldness than it ever can allow."

Such are the properties and merits of the snaffle, which long observation, and not a little experience, have taught the writer of this article to think preferable (generally speaking) to those of the bit; and which he has been therefore induced to point out and recommend with due deference to others, but with a greater deference to truth and justice.

"—Detrahère aufus,

Hærentem capiti multa cum laude coronam."

Berenger's Hilt. and Art of Horsemanship, vol. ii. p. 221, &c.

BIT is also used for a little tool, fitted to a stock or handle, for the purpose of boring. In this sense, we say, the bit of a piercer, an augre, or the like; meaning that iron part of those tools wherewith the holes are bored.

The bit used by the block-makers, resembles the shank of a gimblet, from six to twelve inches long, and from half an inch to an inch in diameter, and has at its end either

a screw, a sharp point, or edge, for the purpose of cutting or boring holes. The *centre-bit* is a bit, having in the middle of its end, a small steel point, with a sharp edge on one side to cut horizontally, and a sharp tooth on the opposite side to cut vertically. Holes bored with this instrument, are not liable to split. The *counter sunk-bit* is a bit having two cutting edges at the end, reversed to each other, which form an angle from the point. *Gouge-bit* is a bit smaller than a centre-bit, with a hollow edge at its end, like a gouge. *Nose-bit* is a bit similar to a gouge-bit, having a cutting edge on one side of the end.

Bit of a Key, is that part fitted at right angles to the shank of the key, wherein the wards are made. See *LOCK*, &c.

BIT is also used in *Commerce*, for a piece of coin current in Jamaica, and valued at $7\frac{1}{2}$ d.

BITS, or *Bitts*, in a ship denote a frame composed of two upright pieces of timber, called the pins, and a cross-piece fastened horizontally on the top of them; used for belaying cables and ropes to. *Bowline and brace-bitts* are situated near the masts; the *fore-jeer*, and *top-sail-sheet bitts* are situated in the fore-castle, and round the fore-mast; the *main-jeer*, and *top sail sheet bitts* tenon into the fore-mast beam of the quarter-deck; the *riding bitts* are the largest bitts in the ship, and are those to which the cable is bitted, when the vessel rides at anchor. The *cable is bitted*, or confined to the bitts by one turn under the cross-piece, and another turn round the bitt-head. In this position, it may be either kept fixed, or it may be veered away.

Bit-Stoppers, are those stoppers that are used to check the cable. See *STOPPER*.

Bitumen

BITUMEN, *Bitumé*, Fr. The bitumens, properly so called, form a species of compound mineral inflammables, of which the following are the characters. 1. By exposure to the air, and the application of heat, they burn with a flame more or less vivid, and leave scarcely any residue. 2. By destructive distillation, they yield a liquid acid, but no ammonia, a variable but small proportion of charcoal being left behind in the retort. 3. They are either liquid, or capable of being rendered so by a moderate degree of heat.

Bitumens may be divided into two families, the non-elastic and elastic. To the former belong naphtha, petroleum, mineral tar, mineral pitch, and asphaltum; to the latter belong mineral caoutchou, and suberiform mineral caoutchou.

§ 1. Non-Elastic Bitumens.

NAPHTHA, *Bergnaphtha*, *Napthe*, *Bitume liquide blanche*, is a substance of a light brown, or wine yellow colour, perfectly fluid and transparent. It is the lightest of all liquids, its specific gravity being = 0.708 to 0.732: it has a strong penetrating bituminous smell; it takes fire with great readiness, and burns with a bluish yellow flame and copious black smoke, leaving no residue. It may be rectified by distillation with water, in the same manner as the essential oils, and then becomes colourless, and weaker in its odour. It does not combine in any considerable degree with either water or alcohol, but unites easily with ether, with turpentine, with caoutchou, and the essential oils. When rubbed with the caustic fixed alkalis, it forms a kind of Starkey's soap. The concentrated sulphuric and nitric acids are decomposed with vehemence upon it, converting it into a solid resinous substance soluble in alcohol. Even the purest naphtha, when exposed to the air, becomes first of a yellow, and then of a brownish colour, acquires a somewhat viscid consistence, and thus passes into petroleum. Naphtha is procured for the most part from very copious springs of this substance at Baku on the shore of the Caspian sea, where it is burnt in lamps instead of oil, and is used medicinally both externally and internally in rheumatic and other complaints. It is also met with in Calabria and some parts of Italy.

PETROLEUM, or *Rock-oil*. *Erdohl*, *Stein-ohl*. *Petrole*. The colour of petroleum is a blackish or reddish brown; it is fluid, though somewhat viscid; it is almost opaque, is unctuous to the touch, and exhales a strong bituminous odour; its taste is pungent and acid. Sp. gr. 0.747, 0.854. Petroleum may be rectified by distillation with water, in which process, the carbon, which thickens and colours it, is left behind in the retort, and a colourless fluid comes over, possessed of all the properties of naphtha. When petroleum is distilled *per se*, there first arises some naphtha, then a watery empyreumatic acid, and lastly a thick dark-coloured oil, a spongy coal remaining in the retort. In its combinations with, and chemical actions on other substances, it perfectly resembles the preceding species. It is found wherever naphtha is, and in many other places among stratified mountains, in the vicinity of coal. In England, Coalbrook dale, and Pitchford in Shropshire, are the principal places where petroleum is found; at the latter place extensive strata of sandstone are saturated with

petroleum, and the naphtha, procured by distillation of the stone, is sold under the name of Betton's British oil, and is esteemed an active remedy in strains and rheumatism.

MINERAL TAR, *BARBADOES TAR*, *Bergthier*, *Goudron mineral*. This substance differs from the preceding only in degree; it is more viscid, more opaque, of a darker colour, and, when distilled, leaves a larger carbonaceous residue. It is found native together with petroleum, and may also be procured by the distillation of coal.

MINERAL PITCH, *Maltha*. The external characters of maltha are extremely similar to those of common pitch; when heated, it emits a strong unpleasant odour. In cold weather it may be broken, and exhibits a vitreous lustre; but when warm it is soft and tenacious.

ASPHALTUM, *Schlachiges Erdpech*, *Asphaltic*. The colour of this substance is black or brownish black; it is light and brittle; when broken, it displays a conchoidal fracture and vitreous lustre; it has little or no odour, unless it is rubbed or heated. It is considerably inflammable, melts easily, and burns away without leaving any residue. It is principally found on the shores of the Dead Sea, in Syria, and in the Isle of Trinidad in the West Indies.

The principal use of asphaltum is as an ingredient in certain varnishes, especially that used by the copper-plate engravers.

§ 2. Elastic Bitumens.

MINERAL CAOUTCHOU, *Elastisches Erdpech*, *Poix minérale elastique*. The colour of this substance varies from yellowish brown to olive brown and blackish or reddish brown. The light coloured is often in a semifluid state, and adheres to the fingers; the olive brown is solid and elastic; the blackish and reddish brown are hard and little elastic. It occurs italcetical, or melting, or in masses. Its sp. grav. in the soft varieties is about = 0.9, and in the hardest and least elastic is = 1.2. It passes into asphaltum.

It is partly soluble in sulphuric ether; but the residue of the solution, after evaporation of the ether, is not elastic; thus forming an essential difference between the vegetable and mineral caoutchou.

This singular mineral has been hitherto only found in the cavities of a lead mine, near Castleton, in Derbyshire, called the Odin mine, accompanied by asphaltum.

SUBERIFORM MINERAL CAOUTCHOU. This substance, when recently cut, exactly resembles fine close cork in its colour and texture; but by exposure for a few days to the air, it becomes of a pale reddish brown colour. It is also sometimes found friable, and passing by decomposition into an ochraceous powder. It has only been found in a rivulet near the Odin mine, whence the preceding is obtained, and appears to differ from it, merely by being penetrated with water. It occurs in nodules of various sizes, some weighing upwards of 13 pounds, the nucleus of which is very commonly the brown perfectly elastic mineral caoutchou. Fourcroy Syst. vol. viii. Brochant. Mineralog. vol. ii. p. 58. Dict. d'Hist. Nat. art. *Bitumes*. Gren. Syst. Handbuch. vol. iii. p. i. Hatchet on Bitumens in Linnæan Transf.

Black

BLACK, blue, in the *Manufactures and Arts*, is the coal of some kind of wood, or other vegetable matter, burnt in a close heat, where the air can have no access: the best sort is said to be made of vine-stalks and tendrils. The goodness of blue-black consists in the cleanness and blue cast of its black colour, and the perfect degree of its levigation.

That this preparation, which is sold in the colour-shops, is no other than a vegetable coal, appeared from the following experiment of Dr. Lewis. (*Comm. Phil. Techn.* p. 358.) Laid on a red hot iron, it burned and glowed like powdered charcoal, and turned into white ashes; which ashes, thrown into oil of vitriol diluted with water, very readily dissolved into a bitterish liquor, the characteristic by which the vegetable earth is distinguished. From what particular vegetable matter this blue-black is procured, experiments, he says, cannot discover: but it appears from those which he recites, that it may be obtained from many, and that the choice of the vegetable subject affects rather the softness or hardness than the colour of the coal. Blue-black, perfectly good, may be prepared in the manner directed for *ivory black*, from the vine stalks, or tendrils, or any other twigs of wood, of an acid taste and tough texture; but the soaking in the oil, prescribed for the ivory, must be omitted.

The painters have *blue-blacks*, *brown-blacks*, &c. which may be made by mixing pigments of the respective colours, with simple black ones, in greater or less quantity, according to the shade required. The dyers also have different blacks, and often darken other colours by slightly passing them through the black dyeing liquor; but the term brown-black is in this business unknown, brown and black being here looked upon as opposite to one another. In effect, the colour called brown-black is no other than that which all dyed black clothes change to in wearing; and therefore it is no wonder that it should be excluded from the catalogue of the dyers' colours. The true or simple blacks, mixed with white, form different shades of grey, lighter or darker, according as the white or black ingredient prevails in the mixt. The black pigments, spread thin upon a white ground, have a like effect. Hence the painter, with one true black pigment, can produce on white paper, or on other white bodies, all the shades of grey and black, from the slightest discolouration of the paper up to a full black; and the dyer produces the same effect on white wool, silk, or cloth, by continuing the subjects for a shorter or longer time in the black bath, or making the bath itself weaker or stronger.

M. le Blon, in his "Harmony of Colours," forms *black* by mixing together the three primitive colours, blue, red, and yellow; and Mr. Castel, in his "Optique des couleurs," published in 1740, says, that this compound black has an advantage in painting above the simple ones, of answering better for the darkening of other colours. Thus if blue, by the addition of black, is to be darkened into a *blue-black*, the simple blacks, if used in sufficient quantity to produce the requisite deepness, conceal the blue, while the compound blacks leave it distinguishable. Le Blon has not mentioned the proportions of the three primitive colours necessary for producing black. Castel directs 15 parts of blue, five of red, and three of yellow; and he observes, that the colours should be the deepest and darkest of their respective kinds, and that a combination should be made to several pigments for each colour; for the greater the contrast of heterogeneous and discordant drugs, the more true and beautiful will be the black, and the more capable of uniting with all other colours, without suppressing them, and even

without making them tawney. Dr. Lewis, in his experiments, has not so far succeeded as to obtain a perfect black by mixing different blue, red, and yellow powders; but he procured very dark colours, such as brown-blacks and grey-blacks.

BLACK, bone, is made of the bones of bullocks, cows, &c. well burnt and ground. To be good, it must be soft and friable, of a glossy cast. It is in considerable use, though inferior in goodness to ivory-black.

The invention of bone, or ivory-black, is attributed to Apelles. *Plin. Hist. Nat. lib. xxxv. cap. 5.*

BLACK chalk. See **CHALK**, and **KILLOW**.

BLACK charcoal. See **CHARCOAL**, and **CRAYONS**.

BLACK, curriers, signifies a tint or dye laid on tanned leather. Tanned leather is so much impregnated with the astringent parts of oak bark, or with that matter which strikes a black colour with green vitriol, that rubbing it over three or four times with a solution of the vitriol, or with a solution of iron made in vegetable acids, is sufficient for staining it black. Of this we may be convinced by dropping a little of the solution on the unblacked side of common shoe-leather. This operation is performed by the currier, who, after the colouring, gives a gloss to the leather with a solution of gum-arabic and size made in vinegar. Where the previous astringent impregnation is insufficient to give a due colour, and for those sorts of leather which have not been tanned, some galls or other astringents are added to the solution of iron; and in many cases, particularly for the finer sorts of leather, and for renewing the blackness, ivory or lamp-black is used. A mixture of either of these with linseed oil, makes the common oil-blackening. See **CURRYING**.

BLACK, dyers, is one of the five simple and mother colours used in dyeing: and given differently, according to the different quality and value of the stuffs to be dyed. See **DYEING**.

Green vitriol strikes a black colour with vegetable astringents, and hence it is the basis of the black dye for cloth, leather, hats, &c. And as solutions of iron with galls, &c. produce the same colour, a method is derived from hence of distinguishing the minutest portions of iron in mineral waters, &c. Neumann.

The substances chiefly employed for producing black colour with vitriol are galls. When a decoction or infusion of the galls is dropped into a solution of the vitriol largely diluted with water, the first drops produce bluish or purplish red clouds, which mingling with the liquor tinge it uniformly of their own bluish or reddish colour. This difference of the colour, says Dr. Lewis (*Com. Ph. Techn.* p. 346.), seems to depend on the quality of the water. With distilled water, or the common spring waters, the mixture is always blue. A minute quantity of alkaline salt previously dissolved in the water, or a small degree of putridity in it, will render the colour of the mixture purple or reddish. Rain-water received from the clouds, in clean glass vessels, gives a blue, but if it be collected from the tops of houses, gives purple with the vitriol and galls. Both the blue and purple liquors, when more of the astringent infusion is added, deepen to a black, more or less intense, according to the degree of dilution; and if the mixture be a deep opaque black, it again becomes bluish or purplish when further diluted. If it be suffered to stand in this dilute state for two or three days, the colouring matter settles to the bottom in form of a fine black mud, which, by slightly shaking

shaking the vessel, is diffused again through the liquor, and tinges it of its former colour. When the mixture is of a full blackness, this separation does not happen, or in a far less degree; for though a part of the black matter precipitates in standing, yet so much remains dissolved, that the liquor continues black. This suspension of the colouring substance in the black liquid may be attributed in part to the gummy matter of the astringent infusion increasing the consistence of the watery fluid, for the separation is retarded in the diluted mixture by a small addition of gum arabic. If the mixture, either in its black or diluted state, be poured into a filter, the liquor passes through coloured, only a part of the black matter remaining on the paper. The filtered liquor, on standing for some time, becomes turbid, and full of fine black flakes: but being freed from these by a second filtration, it again contracts the same appearance, and thus repeatedly, till all the colouring parts are separated, and the liquor has become colourless. The colouring matter, thus separated from the liquor, being drained on a filter and dried, appeared of a deep black, which did not seem to have suffered any change on being exposed to the air for upwards of four months. When it was made red hot, it glowed and burnt, though without flaming, and became a rusty brown powder, which was readily attracted by a magnetic bar; though in its black state, the magnet had no action upon it. The vitriolic acid, diluted with water, and digested on the black powder, dissolved the greatest part of it, leaving only a very little quantity of whitish matter. Solution of pure fixt alkaline salt dissolved very little of it; the liquor received a reddish brown colour, and the powder became blackish brown. This residuum was attracted by the magnet after being made red-hot, though not before; the alkaline tincture, passed through a filter, and mixed with solution of gum vitriol, struck a deep brownish-black colour, nearly the same with that which results from mixing with the vitriolic solution an alkaline tincture of galls. For an account of the result of these experiments, see Lewis, *ubi supra*. See also IRON.

For broad-cloths, fine ratines, and druggets, &c. the dyers use woad and indigo; the goodness of the colour consists in there not being above six pounds of indigo to a ball of woad, when the latter begins to cast its blue flower; and, in its not being heated for use above twice. Thus blued, the stuff is boiled with alum, or tartar, then madderred; and, lastly, the black given with galls, copperas, and sumac. To bind it, and prevent its smearing in use, the stuffs are to be well scoured in the fulling mill, when white, and well washed afterwards.

For stuffs of less value, it is sufficient they be well blued with woad, and blacked with galls and copperas: but no stuff can be regularly dyed from white into black, without passing through the intermediate blue.

Yet there is a colour called *coal black*, or *Jesuit's black*, prepared of the same ingredients as the former, and sufficient of itself without the blue dye. Here the drugs are dissolved in water that had boiled four hours, and stood to cool till the hand would bear it; then the stuff is dipped in it, and again taken out six or eight times. Some even prefer this black to the other. This method of dying black is said to have been invented by the Jesuits, and to have been practised in their houses, where they retained numbers of dyers.

By 23 El. c. 9. nothing of the nature of cloth shall be madderred for a black, except it be first grounded with woad only, or with woad and ancle [blue ind.], unless the madder be put in with sumac or galls; on pain of forfeiting the value of the thing dyed: provided it shall be lawful to dye

any manner of gall-black, and sumac-black [*plain black*], wherein no madder shall be used.

Logwood strikes a black with chalybeate solutions and is employed with these liquors for staining wood black, as picture frames, &c. With the addition of galls, it is used for dyeing cloth and hats black. (Neumann's Works, p. 385.) This black colour is not permanent, though beautiful, any more than the natural violet dye of the *logwood*.

Black may be also obtained by a solution of silver in aqua fortis, when the previous matter stained with this liquor is exposed for some time to the sun and air; and also from solutions of lead in acids, when the subjects to which they are applied are exposed to sulphureous vapours, or washed over with alkaline solutions of sulphur. Calces of lead, melted with sulphur, form a bluish or blackish mass, useful in taking casts from medals. (See CASTS.) Besides, when a solution of silver in aqua fortis is added to a solution of sulphur made in alkaline ley, the silver and sulphur unite and precipitate together in the form of a black powder. See DYING, and STAINING.

BLACK, *earth*, is a kind of coal found in the ground, which, well pounded, is used by painters in fresco. See *Pit-Coal*, and *Fresco*.

There is also a kind of black made of silver and lead, used to fill up the strokes and cavities of things engraved.

BLACK, *German*, or *Frankfort*, is made of the lees of wine burnt, then washed in water, and ground in mills for that purpose, together with ivory or peach stones burnt. Some suppose, that it is the coal of vine-twigs; but this, says Dr. Lewis (Com. Phil. Techn. p. 377.), does not appear to differ, in any great degree, from that of the small branches of other kinds of trees; but the kernels of fruits yield a coal considerably more soft and mellow, easily crumbling between the fingers into a fine meal. That the Frankfort black is no other than a vegetable coal, appeared, from its burning on a red-hot iron, like charcoal powder, into white ashes, and from the ashes, like common vegetable ashes, being plentifully dissoluble by the vitriolic acid into a bitterish liquor, while the ashes of animal substances are very sparingly affected by that acid, and form with it a compound of a different kind of taste.

This black makes the principal ingredient in the rolling-press printers' ink, which see. It is ordinarily brought from Frankfort, Mentz, or Strasbourg, either in lumps or powder. That made in France is more valued than that of Germany.

BLACK *glass*. See GLASS.

BLACK, *harts*, that which remains in the retort after extracting the spirit, salt, and oil of hartshorn. This residue being ground up with water, makes a black not much inferior to that of ivory.

BLACK, *Indian*. See *Indian Ink*.

BLACK, *ivory*, is made of ivory burnt or charred, ordinarily between two crucibles well luted; which, being thus rendered perfectly black, and in scales, is ground in water, and made into troches, or little cakes, used by the painters; as also by the jewellers to blacken the bottom or ground of the collets, wherein they set diamonds to give them their teint or foil. Some recommend soaking the chips or shavings of ivory in hot linseed oil, before it is charred.

There are particular machines and contrivances for burning the ivory for these purposes, by which the colour is rendered more beautiful than that of the coal which remains in the distillation. Neumann.

The goodness of ivory black, which is the finest of all the charcoal blacks, may be perceived by its fulness, without a blue cast; and by the fineness of the powder.

In the manufacture of this black much imposition is practised, so that what is generally sold under this name is no other than the coal of common bones. Being applied to coarse purposes, and sold at a low price, it is very grossly levigated by the hand or horse-mills which are employed in grinding the bones, and so much adulterated with charcoal dust, which gives it a blue cast, that it is wholly exploded from delicate uses, and lamp-black, though inferior with regard to the purity and clearness of the black colour, substituted for it.

The following recipe is given in the *Handmaid to the Arts* (vol. i. p. 140.) for preparing it in perfection. Take plates, chips, or shavings of ivory, and soak them in hot linseed oil; or, if filings are more easily procured, they may be used moistened with the hot oil. Put them into a vessel, which will bear the fire, covering them with a sort of lid made of clay and sand; which should be dried, and the cracks repaired before the vessel be put into the fire. Let this vessel be placed in a tobacco-pipe maker's or potter's furnace, or any other such fire; and let it remain there during one of their heats. When it is taken out, the ivory will be properly burnt; and must be afterwards thoroughly well levigated on the stone with water, or to have it perfectly good, be also washed over. The ivory may be conveniently burnt in a calcining or subliming furnace.

An opaque deep black for water colours is made by grinding ivory-black with gum-water, or with the liquor which fittles from the whites of eggs after they have been suffered to stand a little. Some use gum water and the whites of eggs together, and they say, that a small addition of the latter makes the mixture flow more freely from the pencil, and improves its glossiness. It may be observed, however, that though ivory-black makes the deepest colour in water, as well as in oil-painting, yet it is not on this account always to be preferred to other black pigments. A deep jet-black colour is seldom wanted in painting; and in the lighter shades, whether obtained by diluting the black with white bodies, or by applying it thin on a white ground, the particular beauty of the ivory-black is in a great measure lost.

BLACK, lamp, or lam BLACK, originally perhaps the soot collected from lamps, is generally prepared by melting and purifying resin or pitch in iron vessels; then setting fire to it under a chimney, or other place made for the purpose, lined a-top with sheep-skins, or thick linen cloth, to receive the vapour or smoke, which is the black: in which manner they prepare vast quantities of it at Paris. In England considerable quantities are prepared, particularly at the turpentine-houses, from the dregs and refuse parts of the resinous matters which are there manufactured; but the greatest part is brought from Germany, Sweden, and Norway. Its preparation is described in the *Swedish Transactions* for 1754, as a process dependent on the manufacture of common resin.—The impure resinous juice, collected from incisions made in pines and fir-trees, is boiled down, with a little water, and strained, whilst hot, through a bag: the dregs and pieces of bark, left in the strainer, are burnt in a low oven, from which the smoke is conveyed, through a long passage, into a square chamber, having an opening in the top, in which is fastened a large sack, made of fleasy or thin-woven woolly stuff; the soot, or lamp-black, concretes partly in the chamber, from which it is swept out once in two or three days, and partly in the sack, which is now and then gently struck upon, both for shaking down the soot, and for clearing the interstices between the threads, so as to procure a sufficient draught of air through it. The more curious artists prepare lamp-black for the nicer purposes, by hanging

a large copper pan over the flame of a lamp with a long wick, supplied with more oil than can be perfectly consumed, so as to receive its smoke. Soot collected in like manner from fir and other woods, by burning small pieces of them slowly under a copper pan, is of a deeper black colour than such as is obtained from the same kinds of wood in a common chimney, and little inferior to that of oils. The soot of mineral bitumens, in this close way of burning, appears to be of the same qualities with those of woods, oils, and resins. In some parts of Germany, it is said, great quantities of good lamp-black are prepared from a sort of pit-coal.

The goodness of lamp-black lies in the fulness of the colour, and in its being free from dust or other impurities. The lightness of the substance furnishes the means of discovering any adulteration, if to a great degree; as the bodies with which lamp-black is subject to be sophisticated, are all heavier in a considerable proportion.

This substance is used on various occasions, particularly in the printers' ink; for which it is mixed with oils of turpentine and linseed, all boiled together.

It must be observed, that this black takes fire very readily, and when on fire is very difficultly extinguished: the best method of putting it out is with wet linen, hay, or straw; for water alone will not do it.

A glass tube closely filled with lamp-black has been found to conduct a considerable charge of electricity instantaneously, and with scarce any explosion. But a coating of this substance, mixed with tar or oil, is a perfect non-conductor, and has proved a preservative from lightning, by repelling the electric matter from those parts of the masts of ships which have been covered with it.

Russian lamp-black is prepared from the soot of fir, and is collected at Ochta near St. Petersburg, Moscow, Archangel, and other places, in little wooden huts, from resinous fir wood, and the unctuous bark of birch, by means of an apparatus uncommonly simple, consisting of pots without bottoms, set one upon another, and is sold very cheap. It is three or four times more heavy, thick, and unctuous, than that kind of painters' black which the Germans call "kienrahm," and which is called in Russia "Holland's black." For an account of the spontaneous accension of Russian fir-black, impregnated with hemp-oil, see *Spontaneous INFLAMMATION*.

A *mineral lamp-black* may be procured from pit-coal, or any kind of mineral or fossil coal, by preserving the blackest particles of the smoke arising from it in ignition. Mr. Wm. Row of Newcastle-upon-Tyne obtained a patent in 1798 for his method of manufacturing this kind of lamp-black. See the specification in the *Repertory of the Arts*, &c. vol. x. p. 81.

BLACK paint. See **PAINT**.

BLACK sand. See **SAND**.

BLACK sealing wax. See **WAX**.

BLACK, soot, or chimney, is a poor colour; but ready for painting black draperies in oil. The soot blacks are in general much softer and of a more yielding texture than those of the charcoal kind, and require much less grinding, for uniting them with oily, watery, or spirituous liquors, into a smooth mass; of some of them a part is dissolved by water, or spirits of wine, while none of the charcoal blacks have been found to contain any thing dissoluble. This soluble matter of soots, however, is not black like the indissoluble parts; and in this particular, as well as in the colour of the entire mass, different sorts of soot differ from one another. Thus the soot of pit-coal collected in common chimneys, of itself rather greyish black than of a full black,

being infused separately in rectified spirit of wine, and in water, tinged the former of a transparent reddish colour, and the latter of a paler reddish; while the deeper black soot of wood gave, both to spirit and to water, an opaque, dark brown. See Soot.

BLACK, *Spanijls*, so called, because first invented by the Spaniards, and most of it bought from them, is no other than burnt cork used in various works, particularly among painters.

Blast

BLAST, the term used at iron founderies to denote the column of air introduced into the furnace for the purpose of combustion. Its velocity is occasioned by the impelling power of the blowing machine forcing the whole contents of the air-pump through one or two small apertures called nose-pipes; and, according to the absolute power of the engine, air of various densities will be produced, so that density and velocity are always intimately connected, and mutually implied.

The well-known combustibility of iron, and the indispensable necessity of exciting combustion by the introduction of large quantities of condensed air into the furnace, in contact with ore in various states of maturity as to separation, into contact with iron existing in all the modifications of quality as to carbonation, and into contact with an immense body of ignited fuel, render this subject the most important in the major scale of our manufactures. Unfortunately for art, as well as for science, few practical deductions can be brought forward to establish any one theory of blast; one common principle only is acknowledged, that all reduction in the furnace is in consequence of the combustion excited by the column of air introduced.

To take a proper view of this interesting subject, it will be necessary to submit it to the following divisions.

1st. Combustion, as excited in this particular branch of manufacture.

2d. The nature of the fuel submitted to combustion.

3d. The density of the air.

4th. The quantity.

5th. The properties which follow as a consequence of density and quality.

1st. Combustion in the blast furnace consists chiefly in the rapid reduction of a given quantity of solid fuel, and its accompanying portion of ore, in the shortest possible time. That furnace, and that blast, which can, in a given time, reduce the greatest quantity of fuel, all things else being alike, will always manufacture the greatest quantity of iron. In common, before the introduction of the blast, the furnace is previously filled with alternate strata of coke, iron-stone, and limestone, heated by simple atmospheric pressure to a bright red or white heat, and the iron stone to a melting heat. This temperature is soon increased throughout the furnace, after the blast is applied. The blowing orifices or tuyeres of the furnace exhibit the fuel increasing in whiteness, and the iron-stone rapidly dissolving before the blast, of a blackish colour. At this period, the lava which flows from the furnace, in consequence of the reduction of the ore and lime-stone, is considerably charged with iron, and is of a black, blackish brown, or greenish brown colour. These appearances will continue for twelve, twenty-four, or thirty-six hours, according to the mode of treatment in bringing forward the furnace after blowing. The tuyere (if a bright tuyere furnace) will appear like a blaze of uncom-

monly pure light, at times very offensive to the eye; it soon, however, becomes accustomed to it, and can with facility discern the individual masses of coke, as they are forced away, with the rapidity of lightning, before the irresistible force of the air. The concrete ore and lime-stone are no longer visible; but a fine metallic spray is constantly descending, and, forced from the fuel, precipitates itself to the bottom of the furnace. The scoria formed by the fusion and union of the lime-stone, with the immetallic parts of the ore, is carried before the blast in a similar manner and form, but easily distinguishable from the fluid metal by its buoyancy, want of velocity when impelled, and by its dull colour. In this state, the furnace is deemed in excellent smelting order. The iron is generally revived with little loss; and the colour and purity of the cinder or lava sufficiently indicate the perfection of the separation. When at any time the brightness of the tuyere fails, and becomes dull white or reddish white, then a change is indicated; the iron-stone and lime-stone will again appear in the solid unseparated state, and the change of colour in the cinder infallibly betokens an irregularity in the movements of the furnace. These appearances are so general, as scarcely to admit of an individual exception, and are sufficient to warrant the following explanation.

At the introduction of the blast, the interior of the furnace at the tuyere was simply a mixture of ignited masses of coles and iron-stone, the latter partly semifused, but the greatest part merely heated to a bright red heat. In the descent through the furnace, in contact with ignited coke, the particles of metal in the ore may, by parting with the oxygen, have received a disposition to become revived. The increased temperature creates an additional tendency, by establishing a greater force of affinity betwixt the fuel and the iron. But the metal approaching to its proper state, meeting the current of blast, is immediately subject to a partial combustion. The portion thus oxydated conveys to the lava in proportion to its quantity and oxygenation, the colour already mentioned.

As soon as the continuation of the blast conveys a higher temperature to the superior regions of the furnace, the appearance of the solid matter at the tuyere ceases. The fusion and separation of the metal from the ore are effected in situations more remote from the blast, or chief source of decomposition in a temperature more suited to the nature and existence of the metal. The iron, once formed into a fluid, and its fluidity preserved, its descent to the blast is attended with little or no injury to its carbonation.

To understand this distinctly, it will be necessary to state two curious facts relative to cast iron in a fluid state; and but for the existence of these properties, the manufacture of the metal in open furnaces or vessels would be totally impracticable. 1st. Cast iron, while kept fluid, never decomposes atmospheric air, and never itself becomes oxydated. 2d. The degree of carbonation passed upon the metal at the

moment it enters into complete fusion, continues without diminution or augmentation throughout the whole operation of the furnace; or, in other words, cast iron neither receives nor loses carbon whilst it preserves its fluidity. The first fact explains the reason why the iron is preserved from combustion, when it descends opposite to the current of blast. The second is a proof that the carbonaceous matter is conveyed to the iron in the furnace by a species of cementation previous to fusion; and that after this point, cast iron will not take up any addition of carbon.

To preserve and establish the relation of cementation and fusion in the furnace ensures uniform products. Combustion in this presents us with a gradation of temperature, diminishing from the tuyere upwards through thirty or forty feet of ignited matter. The inferior temperature towards the top of the furnace heats the materials to redness; an affinity is here commenced betwixt the carbonaceous matter and the oxygen of the ore; the latter is gradually removed, and a second affinity is instituted betwixt the de-oxygenated particles of metal and the carbon: this, as the ore descends to higher temperatures, is rapidly increased, and by and by the saturation of the coally principle is complete. As the saturation of carbon always increases the fusibility of iron, the metal of the furnace enters into fusion at a comparatively low temperature, and speedily precipitates, through the high temperatures in the neighbourhood of the blast, to the general reservoir below.

It is not therefore necessary to suppose, that the great volume of air thrown into the furnace, and the great temperature of course excited, are necessary to the manufacture of the iron, so far as it regards quality; this, it is more than probable, may be injured by it, and even the economy of the manufacture itself. Quantity, however, is in general secured; but this is more the effect of mechanical reduction, than of any necessary operation of the blast upon the ore and materials above.

The quicker the body of cokes can be reduced, which occupy that part of the furnace between the point of separation and the tuyere, the greater will be the reduction of the whole, and the greater the quantity of manufactured metal. To this point the whole force of the blast is directed; here the chief part of the decomposition of the atmospheric air takes place; and here the destruction of the intervening cokes is effected, and that always in proportion to the quantity of air poured upon their highly ignited surfaces.

If we assume, with a blast of a certain density, any two points in the furnace, the one as the point of decomposition, and the other of separation and fluidity of the metal, suppose the former at the tuyere, and the other at the lower end of the boshes at A, (See description of BLAST furnace,) then it must be allowed probable, that a change taking place in the density, or even in the quantity of the blast, that change will affect not only the points themselves, but also their relative distances. The point of separation may be brought nearer (and perhaps injuriously so) to the level of the blast, the elevation of which is supposed to remain the same. The contrary may with equal truth be inferred; that if the point of separation is carried to a more elevated situation by a change or increase of temperature, the ore may enter into fusion before it has remained sufficiently long in contact with the ignited fuel, and thereby both the quality and quantity may be injured.

2d. Since pit-coal coke became the staple fuel at the blast furnace, the density and quantity of air deemed necessary to ensure combustion and quantity, have been yearly increasing. The various qualities as to hardness or softness, purity and effect, have given rise to a multitude of opinions, which are the most appropriate quantity and density of air for respec-

tive qualities of cokes. The blast of the furnace, in consequence, has at different places varied from $1\frac{1}{2}$ to 4 lb. of expansive force upon the square inch of the air vessel. Most of the English works are blown with air not exceeding 2 lb. upon the square inch, as being the most proper medium of density, and beyond which the materials would be over-blown. English coal, in general, is soft in its fossil state, but rich in carbon, and free from mixture. In Scotland, where the coal is found in dense strata, and forms heavy coke, the blast is used from 2 lb. to 4 lb. per inch. Those who have adopted dense blasts declare, that quantity of iron is incompatible with a column of air inferior to the measure of their standard. Either the prejudice is very general, or there really must exist a direct analogy between the nature of the blast and the density of the coal.

The operations of the charcoal pig manufactory were conducted with blasts of a trifling density, seldom exceeding $1\frac{1}{2}$ lb. upon the inch, and often under this. Dense blast, it was believed, over-ran the furnace, most probably by exciting too great a temperature, and frequently had a tendency to discharge the materials from the furnace top. There never yet have been any direct experiments made to ascertain upon what this variety of pit-coal depends; whether exclusively from its density, or from containing the carbonaceous matter in more purity or greater disengagement. Perhaps both are necessary to be taken into account, before any satisfactory explanation can be given of the facts now stated and generally admitted.

3d. The density of a column of air depends upon the power of the blowing machine, and the proportion of the area of the steam cylinder to that of the blowing cylinder. Tables of the powers of steam engines, and the diameters of cylinders requisite to condense air from $1\frac{1}{2}$ lb. to 4 lb. upon the circular inch, will be found under the article BLOWING MACHINE. It will appear evident from these tables, that steam cylinders of the same diameter, and working at the same power, when employed to raise air of various densities, do not discharge the same quantity of atmospheric air in any given time. The larger the area of the blowing cylinder, the number of strokes being the same, the greater will be the quantity of air discharged into the furnace. The reverse is the case with blasts progressively more dense; so that any part of an engine's power may be employed, not in raising the true principle of combustion—air, but in condensing a comparatively small body of air, so as to give it additional velocity.

To fix the point, or maximum, of the most profitable density, has hitherto been unattainable. The circumstances, deemed intimately connected with coal, render it necessary to accommodate the blast to the combustibility of the fuel: were this not the case, it would be difficult to overturn the following reasoning, and to exhibit an instance where it might not be found generally applicable. Combustion in the furnace will be excited in proportion to the quantity of air introduced. A blowing machine, that with the same power of steam cylinder threw into the furnace double the quantity of air, though of an inferior density, would reduce a greater quantity of combustible matter than one oppositely constructed; or, in other words, 5000 feet of air per minute entering a furnace would produce greater effects than 3000 feet, although the latter were compressed into nearly half the bulk of the former.

The most plausible theory of blast is to fix upon the lowest density at which the air can be forced into the furnace, and then proportion the diameter of the air-pump to the power of the steam end. Suppose that this could be effected at half the density usually employed, then that part of the

engine's power used formerly to compress the air to 3 or 4 lb. would now be employed in a blowing cylinder of larger diameter, raising per minute, or indeed per stroke, from 100 to 200 cubic feet of air. Opposed to this there stand two formidable objections, resulting from the necessity of using blow-pipes or nozzles of increased diameters, from which to discharge the additional quantity of air, making up in area what is wanting in velocity to discharge the air in a given time. The first is a reaction of the air, so powerful as to issue back from the tuyere with a velocity little short of that at which it enters. This, with nose-pipes of 2, $2\frac{1}{2}$, and from that to 3 inches, is scarcely felt when the blast is soft, and may be entirely obviated by a judicious arrangement of the tuyere iron and nose-pipe; but with pipes from 3 to 4 and $4\frac{1}{2}$ inches diameter, the recoil increases as the squares of the diameters of the blowpipes, and even in dense blasts the recoil increases with the diameter of the discharging pipe. It is therefore probable, that to blow with a nosepipe 4 or 5 inches diameter, so as to have no recoil, a velocity or density of air would be requisite beyond any thing yet in use.

Those who advocate for the use of a soft blast, either upon the plea of their materials, or as being the most advantageous method of using any given mechanical power, frequently feel the full effects of the recoil of a considerable portion of the whole blast. But to obviate this, and to gain the advantage of the whole air, the blowpipe is enclosed in a moveable frame or building, which is made air-tight at every cast, and completely prevents the return of the smallest portion of it. The combustion at these furnaces is carried on with equal effect, and the resulting products in iron equal in point of quantity and quality to those where blasts of double density are used.

Again, at other furnaces, where a soft blast had been originally preferred, the plan of forcing back the recoiled air, in order to make up in quantity what was now deemed to be deficient in density or velocity, has been in vain attempted. The tuyere irons have become immediately heated, and burnt back with violence. The materials would not admit of the tuyeres being raised sufficiently high to prevent the cinder from flowing back into the bag, which connects the large and small pipes, and destroying it. Even in more than one instance, the entire tuyere side of a furnace has been lost in endeavouring to establish this plan of blowing, where either the materials would not answer, or from some misconception in the mode of operating. Where a furnace works uniformly with a dark or honey-combed tuyere, this mode of blowing may be attended with the greatest success. In all new erections, however, the blast ought to possess of itself sufficient velocity not only to enter the furnace, but to ascend through the materials, without admitting of any important recoil.

The second objection, arising as a consequence of the want of velocity, and of being obliged to use pipes of a larger diameter to carry in the full complement of air, arises from a belief that a large pipe never makes the metal of a good quality. This deduction is perhaps not altogether correct; but it seems highly probable, that in the use of a comparatively loose blast, only a small portion of the air passes through the furnace without decomposition. The point of separation may by this means be changed, or perhaps be raised too high for the preservation of the metal, immediately previous to separation. As the increased temperature prevails upwards, the affinity between the particles of metal in the iron-stone, and the carbon of the fuel, may be earlier established, and no ultimate evil consequence, in point of reasoning, ought to ensue. It appears from numerous observations, that the quantity of iron-stone, which a given

weight of cokes smelts, and to the metal of which is conveyed the carbonaceous principle, is considerably dependent upon the diameter of the blowpipe. Supposing the ore of equal richness, the smaller the pipe, the greater burden will the coke carry, and the cheaper will the iron be made per ton, so far as materials are concerned. On the contrary, with large pipes, whatever the density of the air may be, the quantity of coals necessary to manufacture an equal quality of pig iron will be increased, and the cost of the iron is also enhanced. As an equivalent for this, however, the quantity is considerably increased with nearly the same amount of labour; so that it remains a question with the manufacturer, whether the additional cost of coal is compensated by the extra produce of metal he is enabled to bring to market.

4th. The quantity of air discharged into the furnace, under the appellation of blast, depends upon the number of strokes or cylinders which the engine makes per minute, and on the area and diameter of the air pump. This is independent of every consideration of density and increase of power in the steam cylinder, so long as the blowing or air cylinder remains the same, and the engine performs the same discharges; the measure of atmospheric air, which enters the furnace, will remain the same. The rapid improvements, which of late years have been made in the blowing machine, have increased the quantity from 1000 to 4000 feet per minute per furnace; and the quantity or produce in iron has been also considerably increased. We by no means, however, find that the increased manufacture of iron has been in the exact ratio of the quantity of blast thrown into the furnace. Many instances of late years have been noticed during the transition from the old to the improved modes of blowing, wherein the proportion has had little or no similarity.

Fifteen hundred feet of atmospheric air in one minute was found in most situations equal to the manufacture of twenty tons of melting iron; in the same situations, 3000 feet in the same time has never exceeded thirty tons per week; and in one particular trial for two weeks, the discharge of 6000 feet, being the whole produce in air of the engine, the produce in iron never exceeded $36\frac{1}{2}$ tons. In the last case, the quality of the iron was irregular, and the quantity of cokes for each ton of metal thus produced was considerably increased, although the iron was of inferior carbonation.

Without recurrence to the diameter of the air cylinder, and the particular movements of the engine, the same facts have been frequently deduced from the diameters of the nose-pipes. We have frequently seen air discharged under a pressure of $2\frac{1}{2}$ lb. upon each square inch, but with a pipe of $2\frac{1}{2}$ inches diameter, reduce materials, and manufacture good melting iron to the extent of 20, 22, and 25 tons per week; and in the same furnace, and with the same materials, the air discharged by 2 pipes, each $2\frac{1}{2}$ inches, under a pressure of 3 lb. upon each square inch, the produce never exceeded 30 tons of metal of an equal quality, but more frequently 25 to 28 tons. One observation still more direct, and made with a blast of a density equal to $2\frac{1}{2}$ lb. per inch, and discharged by one pipe of $2\frac{1}{2}$ inches diameter, frequently manufactured 22 tons fine melting iron weekly; another pipe was added to the opposite tuyere of the same diameter, and the quantity of metal weekly was never increased beyond 32 tons, and upon an average of six months only 27 tons. These are curious facts relative to the nature and effects of blast, and exhibit the investigation of its principles as a matter of singular importance in the economy of the manufacture.

One remark was made relative to the burden of ore in the last stated fact, that with the small pipe a given weight of cokes smelted and carbonated the metal in 3 cwt. of iron

stone; but after the two pipes were added, the weight of iron-stone, to produce an equal quality of iron, was reduced to 2½, and afterwards to 2¼; producing in the first instance per charge 1½ cwt. of iron upon an average, but latterly not above 1 cwt. and 10 lb. of iron of equal qualities. Another observation, in the same case, with every attention paid as to velocity, quantity, and temperature of air, may be adduced as of equal importance, though somewhat different in its mode of application.

Under a pressure of 2 lbs. a 3½ pipe was found upon the average of 18 weeks to manufacture 20 : 12 : 0 : 0 tons; a 3½ inch pipe, 20 : 5. Upon an average of 11 weeks, and a 4½ pipe, 22 : 5. Their respective areas, and iron produced, will stand in opposition thus :

3½ pipe,	area 10.6625	quantity of metal	20.12
3½ - -	12.25	- - -	20.5
4½ - -	18.0625	- - -	22.17

It is but fair to state that the effects of combustion, so far as it related to the reduction of a quantity of fuel, was not in the same unequal proportion as the quantity of metal to the measure of the air. The quantity of reduction was with the

3½ pipe equal to 25
3½ - - - 31
4½ - - - 38

But the capacity of the fuel to carbonate the original quantity of iron, diminished in nearly the same ratio as the combustion increased; so that the same measure by weight which carbonated 140 lbs. of iron with the 3½ pipe, was unable to carbonate more than from 96 to 100 lb. of the same quality with the 4½ pipe. This observation was made previous to the one last mentioned, and reasoning upon the subject led to the practice detailed in that experiment. It will appear therefore conclusive, that the same body of blast may, with greater advantage and economy, be introduced through two pipes than through one, and this for two reasons. The reduction is equal, and the quantity of fuel reduced, smelts and carbonates a larger portion of metal per charge; but it will appear from both cases equally conclusive, that the capacity of the fuel to convey carbonation is in the ratio of the smallness of the pipe, or the reduction of the quantity of air.

This is in unison with what was stated under the particular "Combustion;" that a large volume of air, so far as it related to the institution of affinity between the coally principle of the fuel, was probably more hurtful to the carbonation than otherwise; but that in so far as it hastened the completion of the affinities, the reduction of quantity, and above all increase of produce, though merely as an agent destroying the superfluous fuel, it may be considered as giving the manufacturer a superiority over his process by means, the extent of which he never could formerly command.

Tradition has, though rather imperfectly, conveyed to us some facts which our forefathers seemed to have understood and practised with better effect than their posterity. In operating with charcoal furnaces, and a blast proportioned to the scanty means then in use for the purpose of producing forge pigs, the whole air was conveyed into the furnace by means of a pipe 2, or at most 2½ inches diameter; but when grey metal was wanted, the same body of air was divided and introduced by two pipes, whose joint capacity was equal to the former.

It appears therefore an enquiry of some importance to those embarked in iron founderies, to ascertain how far this tendency of the fuel to increase the carbonaceous principle proceeds in the ratio of the diminution of the blowpipe. If general observation confirmed the particulars here stated, the effects of

carbonation might be greatly increased, and the quantity perhaps little reduced, by introducing the same quantity of air by means of four, six, or eight small pipes, whose conjoint areas should be equal to the original column of blast.

5. From quantity and density of air, there may and do result peculiar properties of blast, which may affect the operations of the furnace, and which once fully understood may help to explain the facts hitherto unaccounted for, and which we before noticed. Facts resulting from accurate observation would prove an invaluable source of information upon this subject; and it is with regret that we can furnish no perfect aerological table of the different temperatures of air under different densities or degrees of compression. The following, we believe, contains the only collection of temperatures hitherto noted; and as it relates to only one degree of compression, the satisfaction it affords must be only partial.

TABLE of 30 observations made in summer upon various temperatures of air before and during the act of compression, compared with the thermometer in the shade. The air thus ascertained, was received into a magazine containing 2500 cubical feet, free from moisture or damp entirely.

Temperature of the air at the lower valves of the blowing cylinder.	Temperature of the air at the upper valves of the blowing cylinder	Temperature of the air surrounding the receiving vessel.	Temperature of the air within the receiving vessel.	Thermometer in the shade at the time of making the observations.	Increased diff. of temp. between the inclosed air, and average of the two first columns.	Increased diff. between the inclosed air and the temp. of the external air in the shade.
57°	70°	73°	90°	63°	26½°	27°
59	61½	75	87½	64	23	23½
61	71	70½	91	62	25	29
54	68	70	94	66	31	33
57	73	75	95	65½	30	29½
57	72	69	92	64	27½	28
53	70	69	96	64	34½	32
54½	74	70	95½	62	31½	33
56	68½	71	93	61½	30½	31½
57	69	73	97½	65	34½	32½
56	70½	70½	91½	64	28½	27½
52	68	72	88	61	28	27
54	69½	74	86	59	24½	27
51	71	71	90½	62	29½	28½
57	73	79½	94	64	29	30
55	69	73	93	61½	31	31½
56	72	71½	96	65	32	31
56	72	74	97½	66	32½	31½
53	71	70	99	68	37	31
51	73½	70	98	69	35½	29
52	75	72	96½	65	33	31½
55	72	73	94	62	30½	32
47	70	76	94	63	36½	31
51	70	77	91	58	30½	33
49	71	75	93	61	33	32
52	74	74½	98	67	35	31
52½	72½	74	101	69	39½	32
51	73	71	100	74	38	26
54	70	73	102	75	40	27
57	71	74	99½	68	35½	31½

TABLE of 30 observations of the same nature made in the winter months.

Temperature of the air at the lower valves of the blowing cylinder.	Temperature of the air at the upper valves of the blowing cylinder.	Temperature of the air surrounding the receiving vessel.	Temperature of the air within the receiving vessel.	Thermometer in the flue at the time of making the observations.	Increased diff. of temp. between the included air, and average of the two first columns.	Increased diff. between the included air, and the temp. of the external air in the flue.
36	58°	66°	49°	29°	2°	20°
33	54	64	55	30	11½	25
32	51	68	53	29½	11½	23½
33	57	61	50	29	5	21
36	55	60	51½	32	6	19½
31	52	63	50	28	8½	22
29	50	59	48	26	8¼	22
29	49	58	50	27½	11	22½
29	51	59	52	29	12	23
28	50	59	50½	27	11½	23½
30	53½	60	48	28	6¼	20
33	57	61	48	30	3	18
37	56	60	49½	31	3	18½
28	52	62	46	25	6	21
29	51½	59	47	24½	6½	22½
30½	53	59	49	28	6¼	21
33	55	60	53	29	9	24
34	55	60½	56	30	11½	26
32	55	62	54½	27½	11	27
35	56	64	55	30	9½	25
30	50	60	53	30	13	23
27½	50	61	50	28	11½	22
28	50½	62	49	26	9½	23
29	48	58	48	25	9½	23
28	47	58	49	11½	24	25
28½	50	58	47½	8½	21	26½
28	49	60	53	14½	25	28
29	52	61	57	8½	24	27
31½	57	64	55	13½	26	29
29	54	63	56	15½	28	27

There can arise no doubt but that heat is extricated by compression from atmospheric air; and that it is further probable, that the quantity of heat disengaged is in proportion to its condensation. If, therefore, we are allowed to reason upon this subject, we should state the following as a considerable approximation towards truth. It is universally believed and felt, that combustion in the blast furnace in June, July, and August, is considerably diminished, as a consequence of the increased temperature of the air. The metal, in these months, is frequently debased in point of carbonation, and diminished nearly one-half in point of quantity. We shall suppose that this takes place at a temperature of 100, which has been proved to exist under a pressure of 2½ pounds. The reverse of this happens in the cool season of the year, and particularly in the winter months. The furnace then yields the largest quantity of iron, and in the most profitable manner. This, with the same probability, takes place at a temperature of 50 found in the table.

It would therefore appear to result from these, that two-thirds, or one-half of the iron only, is manufactured at a temperature of 100, than in winter at 50. The difference between these degrees of temperature amounts to 50, and most probably in combustion affects the operation as sensibly

as the human frame is affected by a transition of temperature equal or similar. It is not necessary now to state the difference between summer and the denser air of our winter, the circumstances of evaporation and aqueous solution; these shall be particularly attended to in the general process of manufacturing iron. The great difference of temperature arising simply from compression seems to us adequate to explain many phenomena regarding the blast furnace. Our knowledge, however, upon this subject, can only be forwarded by a general collection of facts well ascertained, shewing what are the various degrees of heat made sensible by the compression of the blowing machine under every density; what the difference in temperature, the densities being alike, when the air is received over water, in the air-vault, or in the regulating cylinder. From these it might most probably result, that the higher the density of the air, the greater would be the degree of heat manifested; and it might also follow, that in the ratio of this density, or temperature, when the air was received over water, so would be the evaporation or quantity of water suspended in the air, and of course discharged into the furnace.

This article may be concluded by the following remarks:—That all iron works are not alike affected by the heat of the summer months. Many iron works preserve the quality of the iron, though at the expence of fuel, and with loss of quantity; but at other places no extra quantity of fuel will compensate, either as to quality or quantity, for the want of cool air. Neither situation nor density of blast will explain this curious circumstance; for with blasts of equal density and quantity, works situated not 50 feet above the level of the sea have been found to manufacture a greater quantity of soft iron in summer, than at a similar work, not ten miles distant, situated at least 250 feet higher. At both of these works the air is received over water; and no material alteration in the use of that air is or can possibly be applied. The causes of this difference must be sought for in the nature of the coal and iron-stone used at both works, the investigation of which, however interesting, would prove a most laborious undertaking.

BLAST Furnace, a large conical or quadrangular building used at iron works for smelting iron-stones and ores.

BLAST Furnace, Description of.

Plate (Chemistry) II. fig. 1. represents a blast furnace, and part of the blowing machine constructed upon what at one time was the general plan at iron works.

A, the regulating cylinder, eight feet in diameter, and eight feet high. B, the floating piston loaded with weights proportioned to the power of the machine. C, the valve by which the air is passed from the pumping cylinder into the regulator; its length 26 inches, and breadth 11 inches. D, the aperture by which the blast is forced into the furnace. Diameter of this range of pipes 18 inches. The wider these pipes can be with convenience used, the less is the friction, and the more powerful are the effects of the blast. E, the blowing or pumping cylinder, six feet diameter, and nine feet high; travel of the piston in this cylinder from 5 to 7 feet per stroke. F, the blowing piston, and a view of one of the valves, of which there are sometimes two, and sometimes four, distributed over the surface of the piston. The area of each is proportioned to the number of valves, commonly they are 12—16. G, a pile of solid stone building, on which the regulating cylinder rests, and to which the flanch and stilt of the blowing cylinder are attached. H, the safety valve, or cock, by the simple turning of which the blast may be admitted to or shut from the furnace, and passed off by a collateral tube on the opposite side. I, the tuyere

by which the blast enters the furnace. The termination of the tapered pipe, which approaches the tuyere, receives small pipes of various diameters from two to four inches, called nose-pipes. These are applied at pleasure, as the furnace may be deemed to require an alteration in the volume or density of the blast. K, the bottom of the hearth, two feet square. L, the top of the hearth, two feet six inches square. KL, the height of the hearth, six feet six inches. L, is the bottom of the boshes, which here terminate of the same size as the top of the hearth, only the former are round, and the latter square. M, the top of the boshes, twelve feet diameter, and eight feet of perpendicular height. N, the furnace-top, at which the materials are introduced, or, as it is commonly called, charged; three feet diameter. MN, the internal cavity of the furnace from the top of the boshes upwards, 30 feet high. NK, total height of the interior of the furnace, or working part, 44½ feet. OO, the lining. This is done in the nicest manner with fine bricks, from twelve to fourteen inches long, three inches thick, and tapered to suit the circle of the cone. PP, a vacancy which is left all round the outside of the first lining; three inches broad. This is sometimes filled with coke dust, but more often with sand firmly compressed. This space is allowed for any expansion which might take place, either by an increased volume of the furnace itself in heating, or by the pressure and weight of the materials when descending to the furnace bottom. QQ, the second lining, similar to the first. The object of this is to guard against the entrance of the flame into the mass of common building, by rents which may take place in the first lining OO. R, a cast-iron lintel, on which the bottom of the arches is supported, eight feet and a half long, and ten inches square. RS, the rife of the tuyere arch, fourteen feet high on the outside, and eighteen feet wide. VV, the extremes of the hearth ten feet square. This, and the hoshing stones, are commonly made from a coarse-gritted sand stone, whose fracture presents large rounded grains of quartz connected by means of a cement less pure.

Fig. 7. represents the foundation of the hearth, and a full view of the manner in which the false bottom is constructed.

AA, the bottom stones of the hearth. B, a stratum of bedding sand. CC, passages by which the vapour generated from the damps is passed off. DD, pillars of brick. The letters in the horizontal view of the same figure correspond to similar letters in the dotted elevation.

Fig. 8. AA, horizontal section of the diameter of the boshes; the lining and vacancy for stuffing at M. C, view of the top of the hearth at L.

Fig. 9. Vertical side section of the hearth and boshes, shewing the tympan and dam-stones, and the tympan and dam plates. a, the tympan-stone; b, the tympan-plate, which is wedged firmly to the side walls of the hearth; c, dam-stone, which occupies the whole breadth at the bottom of the hearth, excepting about six inches, which, when the furnace is at work, is filled every cast with a strong binding sand. This stone is surmounted by an iron plate of a considerable thickness, and a peculiar shape, d; and from this it is called the dam-plate. The top of the dam-stone, or rather the notch of the dam-plate, is from four to eight inches under the level of the tuyere-hole. The space under the tympan plate, for five or six inches down, is rammed every cast full of strong loamy earth, and sometimes even with fine clay. This is called the tympan stopping.

The square of the base of this furnace is 38 feet. The extreme height, from the false bottom to the top of the crater, measures 55 feet.

BLAST Furnaces, Construction of.

These furnaces are sometimes built of an external quadrangular form, entirely of sand stone, and lined, in contact with the fire, of the same materials; sometimes they are built conical, entirely of bricks, or with sand stone on the outside, and linings of both common and fine bricks within.

One great desideratum in the construction of furnaces, is to counteract the effects of a powerful expansion, which always take place, to a greater or less extent, after heating, and the introduction of the blast, and which has frequently proved fatal to the existence of the entire fabric.

In the general style of building, all are agreed that the pillars, which support the arches, and of course the whole fabric, ought to be done in the most substantial manner. But beyond the arches, a variety of methods has been adopted to ensure a complete fabric, free from large openings or rents after a few weeks blowing.

Some iron-masters are of opinion, that the same degree of firm building, that is bestowed upon the pillars, ought to be continued to the top, with the addition of binders of flat iron pressing with their edges against the body of the building, or with four screwed bars, still passing through the external building, and forming one square binder, if the shape of the furnace is quadrangular. Another species of binder is used for square piles, made of cast iron of a prodigious strength and weight. The individual pieces forming this binder, have, at their extremities, mortises, which mutually receive each other, with a considerable extra space for the expansion, which is invariably experienced afterwards. Other iron-masters, again, prefer rearing a substantial shell of building, and filling the interior space towards the linings, either with dry bricks, or stones loosely laid together. When the mass of building becomes thoroughly heated by the kindling of the fire, and the introduction of the blast, the interior of the furnace expands considerably, and the action is supposed to be merely confined to the wedging together of the loose parts of the building. By the time that this is effected, the expansion is supposed to have ceased, and the exterior shell of the furnace is preserved entire. Others, equally anxious to form a perfect building, have given an octagonal form to that part of the furnace above the arches, that the binding might be more happily effected. Some have assumed this form, with the addition of semi-circular recesses in the sides of the octagon; their convexes being strongly arched to resist the powerful pressure expected from within.

Still more determined to defy the all-powerful effects of expansion, others have hollowed furnaces from the solid rock, forty to fifty feet high, and lined these immense perforations with fine bricks in the usual form.

Where such a variety of form and of method exists in effecting the same purpose, and where the instances of experiment have been very numerous, every mode of construction can boast of a solitary instance of complete success, excepting in the case of the rock, which was only once attempted, and which, after the introduction of the blast, opened from four to six inches from top to bottom.

There are so many circumstances to be taken into the account, besides the mere form of the building, that unless these are all equally guarded against, the chances are in favour of the furnace opening considerably. If the building is constructed of sand stone, and if this material is carried from the quarry as it is wanted by the workmen, an immense proportion of water is thus introduced, which by a little foresight might have been avoided. Sand stones of common density as to fracture, contain, when taken immediately from the quarry,

from 8 to 10 per cent. of water, and coarser gritted stones from 10 to 12. Taking the average 10 per cent., then in a furnace of equal dimensions to the drawing in *Plate II. fig. 6.* the sand stone of which will weigh upwards of 1200 tons, there will be introduced 120 tons of moisture. This quantity is always considerably increased by the portion of water necessary to reduce the lime to mortar, and frequently augmented by the moist state of the weather during building.

The evaporation of this immense body of water is the source of all the mischief which takes place in the shell of the blast furnace; nor is it much to be wondered at, where every precaution is not used to bring the heat forward in the most gradual manner, preserving the clearness of the vents, and allowing the moisture insensibly to pass away?

In situations where bricks can be obtained, the moisture of the sand stone is avoided, but the great extra quantity of lime, which is necessary to build with bricks, introduces through the medium of the mortar an almost equal quantity of water, as with sand stone. This has been obviated in part by using soft clay in the interior of the walls; but as clay seldom binds to any great extent, the general push of the furnace must be trusted to good binders from without.

In the construction of all blast furnaces, a complete vent-age ought to be preserved by means of narrow flues, or passages proceeding horizontally from the middle of the solid shell, or within two feet and a half of the interior to the outside. These ought to be connected with a circular channel, or gutter, of the same dimensions, proceeding round the circumference of the furnace; so that if any one vent were choaked in the general expansion, the moisture conducted by it might easily vent itself among the other openings. The vents cannot well be too numerous; and as they seldom exceed four inches square, the building cannot be materially weakened by them.

In addition to the horizontal channel of communication, some builders carry up in the main building of the furnace four, six, or even eight perpendicular flues, which communicate with it and the openings that proceed horizontally to meet the external air. See *Plate VIII. figs. 1, 2, 3, 4.*

Either of these methods may be considered as just precautions to insure the existence of the furnace, but adopting them in the fullest and most complete manner, is not always accompanied with similar success. If circumstances formerly noticed concur in occasioning an extra degree of expansion, the pressure of the lining against the common building of the furnace often deranges the systematic order of the vents, pushes the bricks into contact with each other, and smothers for a little while, though to gain more fatal elastic effects, the increasing volume of the vapour.

After such a diversity of opinion upon a subject of such general importance, wherein each respective class of votaries can boast of complete success from its peculiar plan, it may be difficult to point out one more generally attended with good effects than another. The following, however, may deserve the serious consideration of the manufacturer of pig-iron.

Of whatever materials the furnace is constructed, let them possess no more moisture than is sufficient for their proper building. The thickness of the common building not to exceed, at its greatest breadth, $6\frac{1}{2}$, or 7 feet. In the middle of the wall, a space of four or six inches ought to be left clear all the way to the furnace top. Into this vacuity should be introduced small fragments of sand-stone, about the size of an egg and under. When the expansion, proceeding from the fire building of the interior, causes the bricks immediately in

contact to push outwards, the masses of sand-stone are immediately reduced in size, and filling the interstices occasioned by their former angular shape, actually occupy much less room; and now present to the flame or fire, should it be inclined to penetrate so far, a solid vertical stratum of sand, after having secured the expansion of the furnace to the extent of some inches. The effects of the pressure are thus diverted from the shell of the building, and lost in the pulverization of the fragments of sand stone.

The advantages resulting from this plan may be nearly doubled, by using a double lining of fire bricks, as represented in *Plate VIII. fig. 3.* betwixt each of which, and the common building, a similar vacancy should be left; but filled with sharp sand, containing no more moisture than serves to compact it into a firm body. As this moisture becomes gradually expelled in the slow heating or annealing of the furnace, the sand occupies less bulk, or, which is the same in effect, is then susceptible of a greater degree of compression when the general expansion of the furnace comes on. It is evident that the force is here also diverted against the sand in place of acting immediately, with a tendency to enlarge the circumference of the building.

Over and above all these precautions, the annealing or drying of the furnace in a progressive and regular manner ought to be carefully attended to and continued for two or three months at least. Many are blown much earlier, from an anxiety to get to work, and make returns for the great capital necessarily expended in these undertakings.

The same variety of opinions exists in the trade relative to the determined figure and dimensions of the blast furnace, as subsist, with regard to the best mode of building. Its height has, at different times, varied from 20 to 70 feet; and its diameter, at the bores, or widest part, from 8 to 15 feet. It will be easy to trace the source of this indefinite mode of construction, and the uncertainty which must necessarily pervade operations of so much risk and importance.

At the time when charcoal of wood was the common, and indeed, the only fuel used in the blast furnace, the volume and extent of the blast were proportioned to the very imperfect state of the blowing machinery. Long experience had taught the manufacturer what were the proper size and dimensions of his furnace. Many of them were from 12 to 18 feet high, and some of them, where a good water wheel blast existed, reached as far as 28 feet in height.

When pitcoal was introduced into the blast furnace, in the state of coke, to produce similar effects to the charcoal of wood, it was soon found, that in furnaces of equal capacity and height the same effects could not be produced. The ore required to remain in contact with the ignited fuel for a longer space of time, in order, unquestionably, to produce, by attenuated contact, what was deficient in temperature, for the saturation of the ore with coaly matter. This would immediately suggest an increase of the height of the blast-furnace; and if beneficial effects once resulted from a step of this nature, it became a matter of difficulty to say where the progression of height would stop.

Hence, in a few years, arose furnaces of 40, 50, 60, and 70 feet in height. Of the last dimensions, one was erected in Wales. The size of the artificial crater was such, that the strength of the blast was scarcely sufficient to keep the existence of flame visible at the furnace top. After in vain endeavouring to ignite the immense body of materials contained in its vast capacity, the height of the furnace was reduced 30 feet by cutting a hole in its side, narrowing the mouth, and throwing in the materials at the height of 40, in place of 70, feet from the furnace bottom. This was at-

tended with success, and the operations of the furnace proceeded with their usual facility.

After the application of steam engines to raise and condense air, the quantity and strength of the blast became more a mechanical property in the hands of the manufacturer. It was soon discovered that an increased volume of air, by exciting a much higher temperature throughout the furnace, constituted the immediate action of those affinities, which the tall furnace accomplished by a long attenuated contact, and that iron equally carbonated and fitted for the purpose of melting, could be produced by 30 hours contact, as in four days.

The consequence of these gradual discoveries was a general predilection in favour of small furnaces, and at present the bias of the manufacturer seems inclined to this extreme. Where the maximum will be found it is difficult to conjecture, for the ground which the manufacturer now occupies is materially altered from what it was when smelting with coke was first introduced. The perfection to which the blowing machine has attained, forms a striking contrast to the feeble and diminished effects of the bellows in the infancy of the trade. So far as the necessary affinity is increased, and more instantaneously produced in high temperatures, than in those inferior, the manufacturer is differently circumstanced, and commands an extent of means unknown to him in former times. That this superiority will produce equivalent effects in the modification of the blast-furnace, requires but little demonstration. Two facts illustrative of this may, however, be mentioned. Cast steel has of late years been formed directly from bar-iron, by a process which only requires an hour or two to complete, and with small quantities of matter the same may be performed in a few minutes. This is effected by presenting the carbonaceous matter to the iron at a melting temperature. In the usual mode of cementation, blistered steel, by a more attenuated contact and inferior temperature, requires six or seven days to complete, what is here produced in two hours. The difference of temperature in the two operations is equal to 60° or 70° of Wedgewood. The first operation will be considerably shortened, if the cast steel is required to hold much carbon; but if this requisite is necessary in the blistered steel, the length of the cementation must necessarily be protracted. Again, a piece of malleable iron may, by presenting it with a proper dose of carbon, at a high temperature, be converted, in a few minutes, into a mass of the richest carburated cast-iron, which, in a temperature inferior, would have required several months.

The same facts will apply, in part, to the manufacture of pig-iron in the blast-furnace; but an unanimity of opinion and action on this subject is precluded, as well by the prejudices of individuals, as from circumstances arising out of the nature of the materials operated upon in different places.

A furnace has lately been tried at Muirkirk in Scotland, only eight feet diameter across the boshes, in place of its former dimensions, which were ten feet, and 40 feet high. It was soon found, that with the same volume of blast which was formerly applied to the ten feet furnace, very inferior effects were now produced. The combustion apparently was carried to too great an extent, and the materials, owing to this circumstance, entered into fusion before the iron had imbibed a sufficient dose of the coally principle from the fuel. Another great evil which resulted from this diminution of diameter, was a friction, or retardation of the descent of the materials upon the lining of the furnace. This evil was increased and the materials made more bouyant, by the usual volume of air elevating itself in a cone not much more than

half its former area. The consequences were, that the whole mixture of coke, iron-stone, and lime-stone, would have frequently hung for an hour together, or until the blast had cut all the hearth and boshes clear of materials, a slip would have then ensued, and brought with it a large proportion of newly introduced matter. The introduction of this into the fusing point before being properly heated, and long before any affinity had been established betwixt the particles of metal and the carbon of the furnace, invariably changed the quality of the metal, and caused frequent and sudden alterations from grey to white iron.

Upon the subject of height and width of blast-furnaces, it may be finally remarked, that the average height in Britain may be taken at forty feet from the upper surface of the hearth bottom, eleven feet diameter at the greatest width or boshings, and three feet and a half for the diameter of the tunnel-head, or furnace-mouth.

If the proportions of height and diameter in the dimensions of the blast-furnace have given rise to a multiplicity of opinions, the internal structure and shape of the cavity have been no less an ample field for speculation and prejudice. At one time this was conceived so essential to the success of iron-making, that any particular furnace that had made a fortunate run of quantity and quality, was copied with the greatest accuracy of design. The fortunate iron-master ingeniously attributed to the mechanism of his own construction the rich and superior harvest he had reaped in metal, and saw, or fancied he saw, in the curvature of a line, or in the inclination of a slope, the talisman of his good fortune. By prolonging the one, or depressing the other, he immediately inferred that still superior effects would be produced, and that by obtaining the perfection of art in the mere fabrication of structure, every thing that was great and powerful would ensue. This rage continued for many years, and gave rise to an endless variety of shapes, many of which, in their eventual success, had only the merit of originality to boast.

In the establishment of this important and national manufacture, the great fluctuation of opinion as to structure seems to have been the prelude to a subsidence into approved forms, founded upon general principles; and though we may now smile at the indispensable forms which our predecessors, or even contemporaries, annexed to the blast-furnace, yet these alterations of shape and structure lay the strongest claim to our respect and gratitude. The path is now opened, and the ground already beat; from the labours of those who have already gone before us, result the happiest effects; we proceed towards our object, free from the interruption which inexperience always entails; and we may now, by the direct application of principle, perfect with facility what may still be deemed desiderata in this important branch.

The varieties of shape which custom and experiment, from time to time, had annexed to the blast-furnace, may be classed under four distinct kinds. *Plate VII. and VIII.* The following description, characterising the resulting properties and dimensions in the form of each class, will be necessary for comprehending the subject thoroughly.

Plate VII. fig. 1. is the vertical section of the blast-furnace cut across the top of the boshes; the internal shape entirely conical; the external figure a quadrangular pyramid. The construction of this furnace is truly singular; and from this alone great advantages were expected to result. The originality of the principle consists in the double square, or throat. One immediately above the hearth, not represented in this figure, but similar to the square in *Plate IX. fig. 1. B*; and another half way up the cone, four feet in diameter; see *A*.

B, the top of the boshes, 12 feet in diameter.

C, an inferior diameter of 10 feet, previous to the formation of the throat at A.

D, the top of the second row of boshes, of the same diameter as B.

E, the furnace mouth, or termination of the second cone, four feet diameter, and proportioned to A.

F, funnel top for carrying off the flame occasioned by the blast, so as not to interfere with the workmen in filling the furnace.

The dimensions, as to height, are as follow :

From B to C	height	- - - - -	12 feet
C to A	ditto	- - - - -	6
A to D	ditto	- - - - -	6
D to E	ditto	- - - - -	13
Height of the hearth, and first row of boshings, not shewn in the figure, but being the same as <i>fig. 1. Plate IX.</i> measure	- -	- -	15
Height of the bottom stones, packing, and false bottoms,	- - - - -	- -	4

Total height of this furnace from the foundation 56 feet

GG, fire brick lining.

hh, space left for packing.

II, the common building either of sand-stone, or of bricks.

Fig. 2. plan and section of the same furnace taken across the boshes at B.

AAAA, square of the common building 20 feet upon the side, bound by BBBBBBBB, eight cast-iron binders; the number or setts of these requisite, being proportioned, both in strength and dimensions, to the height of the furnace. In common, a full binder is applied every six feet in the height.

The concentric circles represent the various diameters of the interior of the furnace, and are connected each by dotted lines, with their respective places in the elevation.

The reasoning which we believed led to the construction of this furnace, proceeded from a firm belief that the boshes and throat or square of a blast-furnace were of the greatest importance on two accounts. First, because they supported the weight of the materials; and secondly, because they concentrated the heat. These acting conjointly, permitted the least possible quantity of materials to pass, till they dropt away in a state of semi-fusion, or complete separation. In furnaces, however, the cones of which were 30 feet high and upwards, this was conceived impossible to take place for any length of time, to any considerable extent. The height and gravitating pressure of the materials were more than sufficient to counteract the most favourable construction of boshes; and as this could not admit of diminution, the suspension of the materials, and the concentration of the heat must be effected by some other means. This, at one time, was believed to have been completely effected by the scheme of an additional square, and an extra set of boshes; and there is little doubt but that, by converting perpendicular to lateral pressure, the suspension of the materials was reduced at least to one half of its former intensity.

It was not doubted but that the process of smelting and separation would commence, in part, at A; that what escaped fusion and separation in that quarter, would be easily resolved below; and that the process of combustion intensely at work in two different places at once, would greatly facilitate the general reduction, and add greatly to the produce in iron of the furnace. These sanguine expectations were unfortunately never realized, the solitary instance of one furnace only being constructed in defence of this theory, and

that only for a very temporary endurance, is the best proof of the inutility of the plan.

Fig. 3. is the elevated section of a blast-furnace, of which several were built, and from which it was at one time conceived that the greatest advantages were derived. The numerous minute gradations of diameter exhibited in the construction of this furnace, were at one time held in high estimation by many iron-makers; and a plan of the present furnace circulated from the domains of the lucky projector, with as much care and consciousness of rich acquisition, as an antiquary would remove from Herculaneum or Egypt, the precious remains of antiquated obscurity.

It will be extremely easy to trace to its source this particular bias to form, so universally believed in at one time, but now consigned to that oblivion which experience has taught us it deserved at a much earlier period.

It often happens, that when repairing or re-lining a blast-furnace, the manufacturer avails himself of the time thus obtained, to overhaul and repair his engine and blowing machine. The former movements of the machinery may have discovered to him many errors both in movement and construction, which the constant requisite motion rendered impracticable for him sooner to remove. In this way, considerable improvements on the engine and blowing apparatus are frequently made; and when again in motion, may, by increasing the length and number of the strokes in a given time, or by conferring a higher additional working power on the steam piston, increase at the same time both the volume and density of the blast. If the produce of the furnace is increased, which it is highly probable will be the case, then the superior effects are attributed to a few unimportant circles and lines added to the interior of the cone, the acuteness and proportion of which do not survive the blowing of the furnace three days.

In like manner, if a work entirely new, commence operations with a greater advantage of blowing power, and with something original in the shape of the furnace, the consequent effects of the former are industriously attributed to the fortunate construction of the latter, and the grand essential blast is entirely overlooked, and its next important associates coal and iron-stone.

The dimensions of the present furnace are as follow :

Diameter of the cone at A	- - -	3 feet
ditto at B	- - -	4
ditto at C	- - -	8½
ditto at D	- - -	9½
ditto at E	- - -	10
ditto at F	- - -	11
ditto at G	- - -	10

From G to F, the distance in height measures 1 foot

Increase of diameter - 1 foot

F to E, the distance is - 12

Diminution of diameter - 1 foot

E to D, the distance is - 1½

Diminution of diameter - 6 inches

D to C, the distance is - 6

Diminution of diameter - 1 foot

C to B, the distance is - 2

Diminution of diameter - 4½

B to A, the distance is - 4½

Diminution of diameter - 1

Height of the hearth and boshes not represented in the plate - 13

Total height of the cavity of the furnace - 40 feet

or place occupied by the materials - 40 feet
The former descriptions will suffice and apply to this

plate, with equal propriety as to the former, regarding the lining, packing, common building, &c.

Fig. 4. is a plan and section of the same furnace at F in the elevation.

The inner circles represent the various diameters of the interior of the cone, the letters in each corresponding. The two external circles describe the packing and lining; and the circle N exhibits the circumference of the common building of the furnace, which, at this particular section, is 26 feet in diameter.

Plate VIII. fig. 1. is the elevation of the interior of a furnace of a plain construction, and at one time very prevalent at founderies. This fashion was deemed to possess its peculiar merits, and still maintains its form unaltered at some iron-works where the regular tapering cone is not yet admitted. Its inferiority, as to height, is amply made up by an enlarged capacity arising from its diameter.

Diameter at the mouth of the cone	A	-	3 feet
ditto - at -	B	-	11
ditto at the boshes	C	-	12

Height from C to B	-	-	12 feet
from B to A	-	-	14

Height of the boshings and hearth not represented in the figure -

Total height of that part of the furnace occupied by the materials	-	-	37 feet
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FF, represents a view of the vertical method of carrying off the moisture and steam from the mass of building, by means of vents. The number of upright flues vary from four to eight, and have regular communications by means of horizontal openings with the external air, GG. They are generally carried up parallel to the lining, and incline with the general diminution of the cone. The former, or vertical openings, are six inches square, and the horizontal communications four inches square.

Fig. 2. is a plan and section of fig. 1. in which are represented the lining, the vacuity for packing, and eight vents or openings corresponding to those in the elevation. The letters in each figure correspond, and the two dotted circles are meant to shew, that occasionally all the vents communicate with each other by means of a horizontal gutter, or channel, carried quite round the building. This precaution is used lest any of the tubes were to fill up and choak the free circulation of the vapour, that its appropriate quantity may get easily discharged amongst the other openings.

Fig. 3. is an elevated section of a furnace, the interior shape of which has now almost become universal. The regular and uniform descent of the materials which follows, as a consequence of the gradual enlargement of the cone, fully justifies the general partiality in favour of this shape.

Diameter at the mouth, or opening	A	-	3 feet
Diameter at the top of the boshes	B	-	10

The height from B to A	-	-	31½
Height of the hearth and boshes not seen in the plate	-	-	11½

Total height of this furnace	-	-	43 feet
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This form of furnace is not only constructed with a double lining of fire bricks CCCC, and two openings for introducing sand for packing bbbb, but has also an opening DD, from top to bottom, about the centre of the common building. From this, in all directions, proceed small vents, which communicate at a short distance with the open air, as may be seen along the sides of the building.

Fig. 4. is a plan and section of fig. 3. cut across at B.

B, diameter over at the boshes 10 feet.

CCCC, the two circles of fire brick-lining, as seen in the elevation.

bbbb, spaces for receiving packing.

DD, circular vent, or general gutter, from which ramify the horizontal openings.

These are repeated at intervals of four feet in the height, as may be seen in the elevation. In building, DD is filled with fragments of soft sand-stone, which are easily reduced in the expansion of the furnace, and tend, by diverting its real pressure, to preserve the body of the building entire.

A similar want of unanimity of opinion subsists among iron-makers, relative to the general construction of the boshes, their particular height, and most beneficial range. Some contend for flat, others for boshes more vertical, while others again conceive the exertions of those equally successful, who adopt the mean of the two extremes. At different places, and to every possible range, have been attributed the most important consequences in the subsequent process.

Plate IX. fig. 1. represents boshes of the steepest construction.

Diameter at A	-	-	10 feet
Perpendicular height from B to A	-	-	8
Square at - B	-	-	2½

The opinion relative to this form is, that at first blowing, the boshes are productive of a very proper degree of suspension of the materials; but as the pressure of the descent bears in every direction upon the under or bottom part next the square at B, it becomes increased so much, that the weight of the incumbent materials early begin to press too much towards the bottom of the hearth, counteract the regular precipitation which should take place, and impede the ascent and full effect of the blast.

Fig. 4. is a section of boshes approaching to, or indeed may be considered as the opposite extreme. Here the reverse of the fact attributable to N° 1. takes place. The pressure of the descending material is equally distributed over the very flat inclination of the boshes, and there is no more weight deemed to be on the square at A than is equal to a full column of the materials of similar dimensions, left by the direct tendency which the strength of the blast to keep them in a state of partial buoyancy. To counteract these advantages in part, very serious defects are here also imputed. If circumstances unite to increase the tear and wear at A in any uncommon ratio, either by *scouring*, or from a deficiency in the quality of the stone or bricks, the whole of the upper part of the hearth at B B is immediately exposed, and, though composed of a superior quality of sand, will soon follow the direction of the descending current. A pressure of materials then takes place, equal to the whole of the increased space, while the effect of the blast to bear them up is considerably diminished by the enlargement of the original diameter. It will be seen from the plate that the weakness of flat boshes at the top is ill calculated to withstand any accumulating pressure, and that by confining their part of the process to the hearth, the latter much soon, by a similar widening, be entirely destroyed.

Those who wish to steer clear of extremes, or profit by the more adventurous spirit of their neighbours, more generally adopt a mode of boshing that occupies the mean of the two former extremes. This is represented by fig. 3.

Diameter of the boshes at A	-	-	10 feet
Perpendicular height from B to A	-	-	5
Diameter of the square B	-	-	2½

In general, the boshes of blast furnaces are made of the same sand stone with the hearths, but of late fire bricks have been introduced with a considerable indication of advantage.

and permanency. When bricks are used, it is found of utility to make the whole part of the building solid, back as far as the external square of the hearth, so that if the boshes fail in part as to displace one layer of bricks, another surface, equally fresh and entire as the former, presents itself to the action of the fire.

Fig. 2. Ground plan of the top of the boshings of *fig. 1.* A A and B correspond to the same letters in the elevation. The dotted square C describes the form and dimensions of that part of the hearth immediately above the tuyere, as seen in the elevation CC. The large dotted square DD is the external size of the hearth, as seen also in the elevation DD.

Fig. 5. Ground plan of the square and boshings of *fig. 4.*

While we prosecute the detail and history of the construction of the blast furnace, the same diversity of plans formerly noticed comes under review, in every department of the erection. The importance of the hearth is admitted by every class of reasoners upon this subject; and to devise a form better calculated for smelting than another, has been an object of general concern with the manufacturer. Much as may be deemed to depend upon its form and construction, infinitely more benefit is derived from a proper quality of stone, to resist for a given length of time the powerful effects of a continued and unremitting blast. To both of these important desiderata much of the manufacturer's attention has been from time to time directed.

The first singularity that strikes us forcibly in the figure of the hearth, is, that in place of being circular, like the upper parts of the furnace, it is constructed of a square funnel-form, with angles as acute as represented in *Plate IX. fig. 1.* This narrowing form is continued on three sides of the square to the bottom of the hearth, where it generally measures from 22 inches to 24 inches. The top of the hearth, at B or A, *fig. 1.* and 4. or as it is commonly called the square, is never less than 30 inches, nor more than 33. The height of the hearth from E to B, *Plate IX. fig. 1.* 7 feet, and none are made higher. From C to B, *fig. 3.* 6½ feet, which is now reckoned the most advantageous height; and from C to A, *fig. 4.* the hearth measures 6 feet, under which height there are no hearths ever attempted.

The structure of a hearth, properly speaking, consists of three solid sides only, the fourth, or front, is filled up by the tympanon, or key-stone. *Plate IX. fig. 1.* The block E. is generally in one piece, and from four to five feet long, according to the height of the hearth. It descends towards the bottom till within two feet or two feet four inches, and then leaves an opening of similar dimensions, as to height, into the centre of the hearth or funnel, as at letter F.

As the square form in which the hearth is finished cannot last a day after the blast is introduced, and is even frequently destroyed in the act of annealing, or heating, it cannot be essentially necessary to the making of iron. The hearths of all furnaces when blown out, are entirely round, or if waited more upon the tuyere sides, oval. The general usage of the square must have been derived from long acquired habit, or perhaps from the convenience of working and finishing those immense blocks of stone which are still deemed necessary to the perfection of a hearth. The interior of charcoal of wood furnaces was at one time entirely square from top to bottom, so that in the progress of the trade, from smelting with wood to the use of pit-coal, although the general shape of the furnace has been altered, the square figure of the hearth has been retained.

Whatever may have been the utility of this general pre-

dilection in favour of established forms, the advantages hitherto supposed to be derived from this source are now by many doubted, and all those nice speculations relative to the precise dimensions and figure of boshes and squares, threatened with total annihilation. This innovation is not confined to figure alone, but extends to dimensions, and to the nature and bulk of the material necessary for the construction of hearths.

Fig. 1. Plate X. is the section of a hearth and boshings, constructed upon an enlarged principle as to size.

Diameter of the boshes at A	-	-	15 feet
Diameter of the hearth at B	-	-	4
Diameter of the hearth at C	-	-	3

These enlarged dimensions, in place of being square as formerly constructed, are now entirely round, excepting where the tympanon forms the key to the front of the hearth, as may be seen in *Plate X. fig. 2.* where the external circle A A represents the diameter of the boshes, B, the termination of them, or the top of the hearth, and the form at C, a plan of the inside figure of the hearth across the bottom of the hearth at C, *fig. 1.* same plate.

The difficulty of always obtaining a sand-stone well calculated to stand the violent effects of the blast, the frequent great expence incurred, the immense loss of time sustained in cutting out old and putting in new hearths, and afterwards annealing them, has induced more masters to speculate upon the use of bricks of shapes larger than the common forms, made from good fire clay. No permanent advantage has hitherto been derived from this scheme, although it is abundantly obvious, that a successful experiment of this kind would lessen the expence of a hearth greatly, and save at least half the time now required to replace an old one.

Neither have any uncommon advantages resulted from the hearths laid down in *Plate IX. fig. 6.* and in *Plate X. fig. 1, 2, and 3.* While some approve, more are ready to condemn a measure, which has for its object the enlargement of a space before blowing, which too speedily becomes so afterwards. There cannot, however, be any objection to the circular, in place of the square form, unless a little additional workmanship is sustained as such. The matter rests with experience, accompanied by accurate observation, to prove the sanguine hopes of the projectors, or falsify the prophetic forebodings of those who now condemn the measure. The amount of our progress hitherto, in the making of pig-iron, is ascertained with certainty; to assign limits to its ultimate bounds would be presumption. Of one fact, however, we may rest assured, that the perfection of the steam engine, and the consequent command of blast, has alone done more for the manufacture of this article, than all those nice shades of distinction as to furnace taken collectively, which relieve each other in a successive train of minute gradation from one extreme to the other; to all, or to most of which, the most wonderful effects have been from time to time ascribed.

One subject of considerable importance still remains to be discussed, relative to the construction of the blast furnace; namely, the absolute and relative heights of the tuyeres, the dam-stone, and tympanon.

On the subject of tuyeres, the general opinion is, that the nearer the cinder the blast is introduced, the greater is the effect as to the absolute quantity of reduction. But this may be productive of consequences more than sufficient to counterbalance the doubtful advantage of accelerated reduction, either by blowing the cinder from off the surface of the iron, and de-carbonating it, or by the cinder rushing back through the blow-pipe at any top of the blowing machine, and destroying the leather bag which connects the blow-pipe with the main laying pipes. This never

happens but a considerable portion of time is sacrificed, besides the expence of the bag.

In common, the surface of the tuyere plate is laid eight inches above the cinder, or, which is the same thing, above the level of the dam-stone. Some blow at a distance of four inches, others at six and eight, and some again as high as twelve and fourteen inches. However, under some circumstances, the height of the tuyere is determined by the nature of the materials. In these cases, if the tuyere is only raised one inch above its proper height, the bottom of the furnace lumps up immediately, and will invariably rise in the same progressive manner in which the tuyere is heightened.

Plate X. fig. 1. represents the relative proportions of height betwixt the dam, tuyere, and tym, in ordinary cases.

G, the dam, or notch of the dam plate, 17 inches above the level of the bottom at H.

I, the centre of the tuyere 26½ inches from the surface of the bottom, and 9½ inches above the level of the dam.

K, the bottom of the tym plate, 23 inches from the bottom of the furnace, and 6 inches above the level of the dam.

At iron-works where different opinions exist as to the proper or working height of the dam, very different relative heights ensue, regarding the tym and tuyere. The former should always regulate the other two. The height of it is seldom used less than 16 inches, nor more than 28 above the bottom.

Considerable advantages result from placing the tuyere, as to its horizontal position, at a judicious distance from the front or back wall. This is, as in the case of height, often regulated by the nature of the materials. If the furnace, owing to this circumstance, tends to work cold and languid behind, with a propensity to lump at the back wall, the blow pipe ought to be directed as near to the extremity of the hearth backwards as it is possible to get in the tuyere iron; *Fig. 4. Plate X.* letter *a*: but where the operations of the furnaces proceed with ease and facility, the centre of the tuyere should more generally approach the centre of the hearth, as at *b*.

Of late years a new mode of blowing has been introduced, which, from its great prevalency and good effects, seems to bid fair to come into general use. Furnaces till lately were only erected with one arch, or tuyere side, and the blast or column of air introduced by means of one blow pipe; now most of the new furnaces are built with double tuyeres, with two sets of main conducting pipes, and the blast introduced by means of two pipes in place of one.

The general effects and supposed properties of this mode of blowing are attended to under the article blast.

In the mean time, the proper height and distance of the tuyeres, and their relative position to each other, have been subject to endless disputation. *Fig. 4. Plate X.* *a* and *b* shew how, in common cases, the tuyeres are placed to each other in their horizontal range: *a* is placed with its centre three inches from the extremity or back wall of the furnace, and *b* at the distance of nine inches from its centre. That there should be a difference of distance in their horizontal position none are inclined to dispute; but that this should take place in their vertical situation, is by some contended; while others insist that the difference ought never to be less than four inches. *Fig. 6. Plate IX. &c.*

Some less fastidious assert, and with many evidences of sound reasoning on their side, that if the blast is introduced into the furnace, and at a proper distance, to keep the back wall clear, those nice distinctions as to inches go for nothing,

in a region where an instantaneous increase of volume must destroy all repulsion or mechanical contact. This philosophical reason is flatly denied, and the contrary minutely and gravely asserted, that were two pipes placed every way immediately opposite to each other, the action of the opposite columns would retard the velocity of the air, and diminish the real elevated quantity in the furnace, by locking up in mutual opposition a portion of their respective quantities in the laying pipes. There might be some foundation for this conjecture, were the respective nozzles or blow pipes brought into actual contact, or inserted into each other; but to those who consider, that in most furnaces there is never less than four feet of distance between nozzle and nozzle, and the most of the intervening space filled with a column of semifused materials, ignited to the highest pitch of whiteness, this supposition will appear to rest upon very unsatisfactory grounds.

A less scrupulous class of observers and reasoners upon this subject even go the length to assert, that the tuyeres ought to be put in direct opposition, and that this, so far from being detrimental, would be found to possess unqualified advantages. This it is said would result from a certain degree of coolness which the extremity of each column of air confers upon its opposite tuyere iron, and prevent the same from heating and burning. To whatever cause it is attributable, the fact stands in many instances unquestioned, that not half the tuyeres are lost or burnt out, with the double blast, that was formerly destroyed, where the single blast was in use.

Fig. 7. Plate X. represents a tuyere iron, 16 inches wide, and 12 inches high at the wide end, 18 inches long and narrowing at the other end to 4 inches wide, and 4½ inches in height. *Fig. 6.* is a plan of the under surface of the tuyere iron. *Fig. 5.* represents the size and dimensions of the tuyere plate, which when bedded receives upon its surface the tuyere iron, *fig. 7.* This plate is first laid upon a bed of fire clay, with its narrow end towards the hearth, and inclined to rise a little. The tuyere is then introduced upon its surface, height and distance being attended to in the disposition of the plate, and the space betwixt its surface, and the sand-stone of the furnace, rammed very perfectly with balls of good fire-clay mixed with small fragments of fire bricks. When about to blow, the nose or inner end of the tuyere is covered with a very plastic clay, to prevent it from heating and burning away. This is always carefully attended to, and the blast put off at any time to replace it. Should it be neglected at any time, the iron would inflame with such rapidity, that an opening would be instantly made, by which the cohes and ignited matter of the furnace would be recoiled with the greatest violence imaginable.

Fig. 2. Plate XIII. The dam-stone. This is actually the dam, or barrier, which prevents the fluid contents of the furnace from advancing, and making their escape into the sand of the casting house. It is generally made from the same stone as the hearth, but is found still more difficult to stand for any length of time the action of the fluid iron, than the hearth to resist the ravages of the blast.

Fig. 3. dam plate. This is laid against the dam stone with a bed of fire clay interposing, and closes the front of the furnace. Its form is double, so that by turning it serves the purpose twice. It often fails, owing to the constant current of lava passing over the curvature *a*, and deepening it, till the iron flows over along with the cinder.

Fig. 4. the tym plate. This embraces the under end of the tym stone, and the sides of the hearth for three feet up. The thickness at bottom, called the heel, or cod, is preserved from the action of the fire by a strong stopping of clay.

This is replaced at least every cast, and prevents the flame and heated materials of the furnace from being blown forward.

Plate IX. *fig. 4.* is a ground plan of the arch pillars, hearth, tuyeres, and vents of a blast furnace.

A, the hearth, or particular spot where the fluid metal is collected.

B, the dam-stone.

C, the fall, or opening, by which the metal is discharged. After the cast it is filled with sand, which soon hardens and presents a very close texture to the fluid metal within. At the following cast it is cut carefully down, till the bar penetrates to the quick. A circular incision is then made, and the metal flows out of the orifice in a connected round stream, into the runner or channel made in the sand.

d d d d, four vents or openings which communicate with the false bottoms. Plate I. *fig. 2.* These serve to convey the damp from the furnace bottom, and by being run out into the external air, two in the front of the hearth, and one at each tuyere, indicate by their temperature, and the quantity of steam or vapour which they emit, the real state of the bottom below.

DD, the two pillars which support the front arch; they, at the same time, serve as abutments to one leg of each of the tuyere arches. The arch at the front is 15 feet wide and 15 feet high, and inclines to the centre of the furnace, in the same manner as the side walls of the pillars approach.

E, main or back pillar built entirely solid.

FF, vent holes six inches square, carried up from the foundation, and brought forward to meet the open air every four or five feet.

G G G G G G, tops of the pillars covered with cast iron plates, for receiving three large cast iron lintels, 10 feet long, and 10 inches square. These serve to give solidity to the arch, and support the lining and boshes of the furnace. *Fig. 8, 9,* different forms of tuyere pipes.

BLAST-FURNACE.—History of its Origin and Progress.

In detailing the progressive history of the blast furnaces, it is necessary to premise, that in this country it has undergone a revolution, of which we meet with no similar instance in other countries.

The most natural and abundant fuel which presents itself to mankind in their progress toward civilization, is that furnished by the numerous and extensive forests, which generally occupy the surface of a wide and uncultivated country. These, in the history of all nations, have been early appointed to domestic uses, and to the comfort of individuals. As a country became more populous, and the spirit of civilization increased, other advantages resulted from the general use of wood as fuel. The amelioration of climate, and the clearing of large tracts of land, making it subservient to the purposes of agriculture, were not the smallest benefits thus derived. As the progress of knowledge began to devise and establish regular manufactories, to supply the wants of the thriving community, the same sources of combustion were opened to the manufacturer and the artisan. These, as they became successful, were only preludes to other establishments more extensive, more lucrative, and entailing wants more difficult to supply. Among others the smelting of metals was no doubt of early origin, and equally dependent upon the woodland counties, in the immediate neighbourhood of the ores. In this class we can trace no metallurgical operation so hostile to the existence of wood, as an extensive manufacture of iron. If this manufacture, owing to the great and unexampled prosperity of the country, in place of remaining stationary, or exhibiting symptoms

of decline, arising from a want of consumption of the article, has increased in capital, in extent, and riches beyond all precedent, wood, the base of the manipulation itself, depending only upon a stock rapidly declining, the existence of which was frequently incompatible with the views and interest of the landed proprietor, must soon have been annihilated, and the art of making iron lost to the community.

In this singular situation was Great Britain placed from the reign of Charles II. to the middle of the last century. The increasing manufactures, commerce and general prosperity of the country called loud for an additional supply of articles fabricated from iron, while wood, the foundation of the whole art, was rapidly declining in point of quantity, without the most distant prospect of ever being again renewed. Pit coal had been long before the latter period suggested as a substitute, but prejudice, interested views of established capitalists, and above all, a want of command of mechanical power, had prevented any successful operation from being established in this new department of iron making. No sooner, however, were these barriers to improvement broken through, and a change of fuel in the blast furnace found to be attended with profitable effects, than the languishing state of the trade began to revive, and improvements succeeded each other, with a facility new and astonishing. In fifty years the revolution was complete whether the consideration regards the increase of the manufacture, the general use of pit coal in the blast furnace, or the almost total annihilation of the charcoal mode of making iron.

It is uncertain at what period the manufacture of iron commenced in Britain. It is probable, that the working of the tin mines of Cornwall, by the Phœnicians, would introduce into the country a class of men skilled in all the then known metallic ores, capable of appreciating their true value, by converting the riches of an unexplored country, either to their own immediate necessities, or to the conveniences of the unskilful inhabitants. The invasion of England by the Danes, and their consequent establishment, would most likely add to the former stock of knowledge, in the art of mining and fusing iron ores. Whatever truth there may be in this conjecture, the fact stands unquestioned, that in several counties in England large heaps of scoria are found with an accumulation of soil sufficient to bear large trees. These have been from time immemorial called "Dane's cinders." So early as 1620, Dudley remarks, that large oaks were then found in a state of decay upon the tops of some of these hills of scoria. It is not, however, probable, that these cinders were the product of the blast furnace. At a period so remote as that, wherein these heaps of scoria must have been accumulated, the labours of the iron maker were chiefly directed to the fabrication of small portions of malleable iron in *foot blasts* and *bloomeries*. The art of moulding and casting in iron was either totally unknown, or so very rude, as to excite no interest in favour of prosecuting this fine branch of art. If pig or cast iron was at all formed, it was merely of the most infusile nature, for being speedily converted into malleable iron. It was not till long afterwards, when improvements had taken place in the rude machinery of the times, and a division of labour seemed to be productive of many advantages, that different furnaces existed: one for the making of pig iron, and another for the conversion of it into malleable iron. This first gave rise to the blast furnace, which, properly speaking, was an improvement resulting from the knowledge of the advantages derived from a division of labour. After the appropriation of the blast furnace to the exclusive manufacture of pig iron, the manufacturer would soon discover, that the products of

his furnace were frequently different from each other. Experience and observation would soon enable him to decide, from whence this had its origin. A small additional quantity of fuel, beyond that he formerly used for forge-pig-iron, he found, would confer a degree of fusibility upon the metal that immediately pointed out the practicability of casting it into shape. Moulding from thence would most likely ensue, and become equally an appendage to the blast furnace as was the bar-iron forge. As this new manufacture became familiar to the proprietor, he would immediately find his interest in dividing the product of his blast furnace into grey melting iron or into forge pigs, as the exigencies of his moulding shop, or forge required.

If credit could be given to the "Metallum Martis" of Dudley, in the 12th year of James, anno 1615, there were at that period not less than 300 blast furnaces for smelting iron-ore with charcoal, each of which had fuel, upon an average, for 40 weeks per annum. The average produce in pig-iron at each furnace of 15 tons per week, or 600 tons per annum, makes the total yearly quantity 180,000 tons, being a greater quantity than has ever since been manufactured in Britain.

However much this quantity may be exaggerated, yet it is highly probable, that even at this early period, the iron business in general, and the particular operations of the blast furnace, had obtained an eminent rank in the manufactures of the country. The progress of agriculture, and the increase of population under the reign of the peaceable James, had taught the husbandman and the proprietor the value of cultivated fields. The great consumption of wood for the navy and iron-works had greatly exhausted the principal forests of supply; tracks of country became cleared, and as the spirit of cultivation increased, the annual quantity of fuel for the manufacturing of iron diminished.

It is probable that Mr. Dudley, in estimating the quantities produced from each furnace, fixed his average from the winter and spring months, when water was plentiful, and he seems not to have made sufficient allowance for the occasional stoppages in summer, during the time of cutting and collecting the wood for the ensuing wet season. If, therefore, in place of making 600 tons yearly, the furnaces of these days are supposed to have made each, upon an average, five tons per week, or making a little allowance, 250 tons yearly, which is surely nearer the truth, this still leaves an annual amount of manufactured pig-iron equal to 75,000 tons, which, exclusive of the operations of the forge, forms a very respectable staple at that early period of the history of our manufactures.

Pit coal had been long known before this period, and wrought at Newcastle prior to the year 1272. Annually vast quantities of it were exported to Holland and the Low Countries, for the use of the smithy, and other manufactures requiring an intense and continued heat. Yet in England prejudices ran so strong against its application to the manufacture of cast-iron, that the projectors of this original undertaking met with every obstacle which the narrow unenlightened minds of the established manufacturers could devise.

James granted several patents for the exclusive right of manufacturing iron with pit coal. None of the projectors, however, were successful, till the year 1619, when Dudley succeeded in making coak pig-iron in a blast furnace, though only at the sparing rate of *three tons per week*. At this period many of the iron works were at a stand for want of wood, and the consequence was an advance upon the price of iron: this rendered it a lucrative business to those manufacturers whose supply of wood was still undiminished, and of course made them hostile to any innovation, whereby the present price of iron was likely to meet with a reduction.

This period of prejudice, so unfavourable to innovation in the iron business, was followed by one more general and more calamitous for the nation: amidst the distraction occasioned by civil war, neither innovation nor improvement could be expected. Patents, however, were granted to some during the common-wealth, for the exclusive manufacture in the new way, in one of which, it was at the time believed, that Cromwell was a partner: these partly shared the same fate with the first inventor, and none succeeded in establishing a manufactory either of extent or certainty. In 1663, we find Dudley applying for his last patent, and setting forth, that at one time he was capable of producing seven tons of coak pig-iron weekly, with an improved furnace 27 feet square, and bellows, which one man could work for an hour without being much tired.

It was not, till impelled by necessity, arising from the rapid decline of the annual growth of timber, that pit coal became an object of universal estimation. When improvements on machinery had attained a pitch of certainty, and experience had taught the mechanic the manifold advantages of the steam engine; the adventurous manufacturer found he possessed an extent of means to which he was formerly a stranger. Small furnaces, supplied with air from leather bellows, blown by oxen, horse, or human labour, became exploded, and an increase of size took place, together with an increase of the column of blast necessary to excite combustion.

At this eventful era in the history of the blast furnace, when the ameliorating hand of agriculture was progressively sweeping before it, what remained of the once immense tracts of woodland dedicated to the supply of the blast furnace; when the general improvement in machinery, and the introduction of the steam engine threatened to give new life and impulse to manufactures in general, the iron-business seemed dwindling into insignificance and contempt. The demand of the country increased for the manufactured article, particularly bar-iron, while every year saw a gradual but steady diminution of the annual quantity. Recourse to foreign markets was had for a supply of that article, of which this country once was the greatest exporter, and the immense annual importations from Russia and Sweden may date their origin from that period. The flourishing and extensive detail of Dudley no longer existed, and the 300 blast furnaces of his day were now diminished to 59 in all; the total amount of whose annual produce was 17350 tons, or nearly 300 tons to each furnace.

LIST of the Blast Furnaces in England and Wales immediately before the introduction of pit coal, as a substitute for the charcoal of wood; the particular counties in which they were situated; the collective quantity of iron manufactured in each county, and the produce of each particular blast furnace.

Counties.	Furnaces in each county.	Names of the Furnaces.	Total num of furnaces.	Iron made at each furnace.	Iron made in each county.
Brecon	1	Ynyfedwyn	-	1	200
	1	Llanthy	-	1	400
	2	furnaces.			600
Glamorgan	1	Neath	-	1	200
	1	Berfilly	-	1	200
	2	furnaces.			400
		Carried forward	4		1000

Counties.	Furnaces in each county.	Names of the Furnaces.	Total num. of furnaces.	Iron made at each furnace.	Iron made in each county.
Brought forward					
Carmarthen	1	Kidwelly	1	—	100
=					
Cheshire	1	Valercydlle	1	600	
	1	Lawtome	1	600	
	1	Dodington	1	500	
	3	furnaces.		1700	
=					
Denbigh	1	Waddoch	1	300	
	1	Ruabone	1	250	
	2	furnaces.		550	
=					
Derby	1	Staveley	1	150	
	1	Foxbrooke	1	150	
	1	Wingworth	1	200	
	1	Wanely	1	300	
	4	furnaces.		800	
=					
Gloucester	1	Blabney	1	600	
	1	Elmbridge	1	500	
	1	Flaxley	1	700	
	1	Redbrooke	1	600	
	1	Ditto	1	200	
	1	Sidney	1	250	
=					
Hereford	6	furnaces.		2850	
	=				
	1	St. Waynarde	1	300	
	1	Bingwood	1	450	
	1	Bishopwood	1	600	
=					
Hampshire	3	furnaces.		1350	
	=				
Hampshire	1	New Forest Firne	1	—	200
	=				
Kent	1	Lamard	1	100	
	1	Barcline	1	100	
	1	Horfden	1	100	
	1	Handberft	1	100	
	4	furnaces.		400	
=					
Monmouth	1	Pontypool	1	400	
	1	Ditto	1	500	
	2	furnaces.		900	
=					
Nottingham	1	Kirkby	1	—	200
=					
Salop	1	Salop	1	400	
	1	Bowlden	1	400	
	1	Willy	1	450	
	1	Ditto	1	200	
	1	Leighton	1	400	
	1	Kimbrotten	1	250	
=					
Salop	6	furnaces.		2100	
	=				
Carried forward				37	12150

Counties.	Furnaces in each county.	Names of the Furnaces.	Total num. of furnaces.	Iron made at each furnace.	Iron made in each county.
Brought forward					
=					
Stafford	1	Bradley	1	400	
	1	Wincheath	1	600	
	2	furnaces.		1000	
=					
Worcester	1	Rewdly	1	200	
	1	Hated	1	500	
	2	furnaces.		700	
=					
Suffex	1	Ashburnam	1	500	
	1	Bubley	1	100	
	1	Bread	1	100	
	1	Robert's bridge	1	100	
	1	Bery	1	100	
	1	Darville	1	100	
	1	Heathfields	1	100	
	1	Crunfuple	1	100	
	1	Lord Pelham	1	100	
	1	Ditto	1	100	
=					
Suffex	10	furnaces.		1400	
	=				
Warwick	1	Alton	1	400	
	1	Pooliband	1	300	
	2	furnaces.		700	
=					
York	1	Band, upper,	1	200	
	1	Band, lower,	1	200	
	1	Barnby,	1	300	
	1	Rosbley, upper,	1	200	
	1	Ditto, lower,	1	200	
	1	Chappel	1	300	
=					
York	6	furnaces.		1400	
	=				
				Furnaces 59	17350

Tons. cwt. qr.

Annual average for each furnace 294 1 1

By this statement it is evident, that the manufacture of pig-iron had diminished during one hundred to one hundred and thirty years preceding, upwards of 50,000 tons annually. Fortunately for the existence of the trade, the application of good going, and what, at that time, would be reckoned powerful, steam engines, about the year 1750, for raising and compressing air, were introduced at some places where abundance of materials was found without water for turning machinery. The manufacturer now found that his produce could be increased by enlarging the diameter of his steam cylinder, or perfecting the vacuum under the piston; and it was soon discovered, that these increased effects alone were requisite to the formation of pig-iron, in profitable quantity from the coke of pit-coal; nor is it to be wondered that this secret remained so long a mystery. The small quantity of air that was formerly requisite to ignite a charcoal furnace, whether from the great inflammability of the fuel, or the smallness of its capacity, was constantly before the eyes of the manufacturer. He had more often felt the effects of over-blowing, than under-blowing his furnace; and it is highly probable, that pit-coal, being deemed every way

inferior, an unusual timidity would precede any movement that might have for its object the enlargement of the column of air or the increase of its density.

This, however, once done away, there seemed no end to the quantity of air that a coke blast furnace could with propriety receive before any bad consequences ensued. Density, however, was found inimical to quantity, and the same law was at last discovered to hold good regarding pit coal as with wood, that the softer qualities could be over blown, while the more dense and compact strata remained undiminished before a heavier blast.

The celebrated foundry of Carron was begun about the year 1760, and as was the custom of the times, the operation of blowing was performed by large bellows moved by means of a water wheel. Pit coal was the staple fuel in view, but the scanty supply of air, and its want of density, seldom permitted the produce of the furnace to exceed 10 or 12 tons weekly, and frequently, in summer, the quantity was reduced even below this. The company collected immense quantities of charcoal wood, and found their blast much better calculated for the operation of smelting with it, than the unflammable pit coal obtained in their neighbourhood. Experience, however, gradually unfolded means of adopting machinery, more calculated to the nature of the coal fuel, more powerful wheels were constructed, the bellows was abandoned, and in their place large iron cylinders were introduced blowing both up and down. A larger column of air of triple or quadruple density was obtained, and effects equivalent to these great improvements followed at the blast furnaces. The same furnaces that formerly yielded 10 and 12 tons weekly, now sometimes produced 40 tons in the same space, and on the average in one year not less than 1500 tons of metal.

From the period (1750 to 1760) that pit coal coke was applied as a substitute for wood charcoal in the blast furnace, the iron trade began immediately to revive, and its progress in England and Wales, in a period of 30 years, was truly astonishing. The general use of pit coal, most unquestionably, occasioned an earlier relinquishment of many of the charcoal works, than would have otherwise been the case, but the collective manufacture had so much increased, as to render this an object of trifling importance.

The following is a correct statement of the annual manufacture of pig-iron in England and Wales in the year 1788:

Charcoal Blast Furnaces.	No. of Furnaces.	Tons each.	Total in each County.
Gloucestershire	4	650	2600
Monmouthshire	3	700	2100
Glamorganshire	3	600	1800
Carmarthenshire	1	400	400
Merioneth	1	400	400
Shropshire	3	600	1800
Derbyshire	1	300	300
Yorkshire	1	600	600
Westmoreland	1	400	400
Cumberland	1	300	300
Lancashire	3	700	2100
Suffex	2	150	300
Total of charcoal furnaces	24		13100
		Tons, cwt. q.	
Average produce from each furnace	-	545 16 2	
Former average produce	-	294 1 1	
		251 15 1	

Increased produce per furnace, from the year 1750 to 1788, attributable entirely to the general improvement of machinery, and the introduction of the steam engine, 251 tons, 15 cwt. 1 qr.

	Tons.
About the year 1750 the annual quantity of charcoal pig-iron manufactured in England and Wales amounted to	17350
In 1788 the same was	13100

Decrease in charcoal iron betwixt 1750 and 1788 4250

attributable chiefly to the decrease of wood, but also in part owing to the use of pit coal as a substitute in the furnace.

Coke Pig Blast Furnaces in 1788.	No. of furnaces.	Tons at each.	Total in each County.
Shropshire	21	1100	23100
Staffordshire	6	750	4500
Derbyshire	7	600	4200
Yorkshire	6	750	4500
Cumberland	1	700	700
Cheshire	1	600	600
Glamorganshire	6	1100	6600
Brecknockshire	2	800	1600
Staffordshire 3 new furnaces expected to blow same year	3	800	2400

Total furnaces and coke pig-iron manufactured in 1788 } 53 48200

An article entirely new, which though not discovered, was rendered a profitable and highly useful manufacture in the last 30 years.

Average produce at each furnace 907 tons.

	Tons.
Total of charcoal iron	13100
Ditto of coke pig-iron	48200

Total of pig-iron manufactured in England and Wales annually } 61300

At the same period in Scotland there were erected, and in blast, charcoal furnaces in the west Highlands, viz.

	No of Furnaces.	Tons each.	Total.
Goatfield	1	700	700
Bunawe	1	700	700
Coke pig furnaces, viz.			
Carron	4	1000	4000
Wilfontown, or Cleugh	2	800	1600

Total quantity of pig-iron manufactured in Scotland } 1 7000

Average produce for each furnace annually 875 tons.

Total quantity of pig-iron made in England and Wales	77	61300
	85	68300

Annual quantity manufactured immediately preceding the introduction of pit coal for furnace fuel } 59 17350

Annual increase in 30 years 26 50950

The period of 1788 or 1790 may be called a new æra in the manufacturing of pig-iron. The double power engine of Mr. Watt had now become more general, and was

yearly finding its way into blast furnace works. The regular and increased effects of this very powerful machine were soon felt in most of the iron counties. The produce of the furnaces in metal greatly increased as to quantity, and as they became more prosperous, stimulated others to engage in similar undertakings. New works were yearly projected, and several blowing furnaces annually added to the former list: so that in eight years the manufacture of pig-iron had nearly doubled itself.

The following table is a curious illustration of this fact. It was drawn up as an authentic document of the returns made from all the blast furnace proprietors in Britain, of the number of their furnaces, and the annual quantity of pig-iron manufactured at their respective founderies. These returns were made at a time when it was in the contemplation of the legislature to impose a tax upon pig-iron, and are copied from Dr. M'Nab's letter to the chairman of the committee of the house of commons upon the subject of the coal trade.

NAMES of all the FURNACES in Great Britain, with the Excise Return of the Quantity of Pig Iron made in 1796; the Quantities supposed and calculated upon; and the Returns of the Quantities really made.

NAMES OF FURNACES.	No. of Furnaces.	Division.	Excise Return.	Supposed Quantity.	Exact Return.	From whom this Information was received.
Apedale, - - -	1	Chester	2100	1000	728½	T. S.
Silverdale, - - -	1	Do.	2600	1200	1230	Ditto.
Bear post, - - -	1	Cumberland	2080	1200	240	W. R.
Dudden, - - -	1	Do.	1664	400	325	E. K.
Newland, - - -	1	Do.	700	700	700	Excise.
Backbarrow, - - -	1	Do.	700	700	769	E. K.
Dale Abbey, - - -	1	Derby	474	474	443	A. R.
Morley Park, - - -	1	Do.	728	728	728	Excise.
Butterby, - - -	1	Do.	936	936	936	Do.
Flaxley, - - -	1	Gloucester	360	360	360	Do.
Forest of Dean, - - -	1	Do.	20	20	20	Do.
Abbey Tintern, - - -	1	Hereford	70	70	70	not exactly known
Bishopwood, - - -	1	Do.	500	500	947	E. K.
Cornbrook, - - -	1	Do.	1000	1000	482	W. R.
Bringingwood, - - -	1	Do.	500	500	250	Do.
Leighton, - - -	1	Do.	780	780	780	Excise.
Bowling, - - -	2	Leeds	2000	2000	2000	J. H.
Wibsey Moor, - - -	2	Do.	2000	2000	2500	Do.
Shelf, - - -	1	Do.	1000	1000	1140	Do.
Birkenshaw, - - -	1	Do.	780	780	846	Do.
Renishaw, - - -	2	Lincoln	500	500	705	J. W.
Old Park, - - -	3	Salop	11332½	6240	5952	W. R.
Horsehay, - - -	1	Do.	4927½	2080	1458½	Do.
Lightmoor, - - -	3	Do.	8946	6240	3498½	Do.
Coalbrook Dale, - - -	3	Do.	7175	4162	2659½	Do.
Madely Wood, - - -	1	Do.	3777½	2080	1856½	Do.
Jackfield, - - -	2	Do.	7086	4160	1820	Do.
Benthal, - - -	1	Do.	2367½	1600	1334	Do.
Wiley, - - -	1	Do.	3702½	1600	1554½	Do.
Brofely, - - -	1	Do.	1775	1400	1076½	Do.
Ketley, - - -	3	Do.	7590	6240	5068½	Do.
Snedshill, - - -	2	Do.	4730	3400	3367½	Do.
Donnington Wood, - - -	2	Do.	4720	4160	3323	Do.
Chesterfield, - - -	1	Sheffield	940	940	940	Excise.
Little Brampton, - - -	2	Do.	1800	1800	1560	Messrs. S.
Winger Worth, - - -	1	Do.	1274	1274	1274	Excise.
Stavely, - - -	1	Do.	1000	1000	761	W. W.
Park, - - -	1	Do.	1092	1092	853	J. W.
Chapel, - - -	1	Do.	1456	1456	1456	Excise.
Horncliffe, - - -	2	Do.	1092	1092	712	J. W.
Eltham, - - -	1	Do.	800	800	950	Do.
Brelton, - - -	1	Do.	250	250	250	Excise.
Holmes, - - -	3	Do.	6000	6000	2000	J. W.
Ashturnham, - - -	1	Sussex	172½	173	173	Excise.
Clydach, - - -	1	South Wales	1820	1820	1625	E. K.
Carried forward -	63		107,318½	77,905	61,722½	

NAMES OF FURNACES.	No. of Furnaces.	Division.	Excise Return.	Supposed Quantity.	Exact Return.	From whom this information was received.
Brought forward,	63		107,318½	77,905	61,722½	
Blandare, - - -	1	South Wales	1404	1404	1500	E. K.
Blanavon, - - -	3	Do.	5460	5460	4318	Do.
Sirhowy, - - -	1	Do.	1820	1820	1930	Do.
Beaufort, - - -	1	Do.	1560	1560	1660	Do.
Peuyca, or Ebbervale, -	1	Do.	1560	1560	397	Do.
Hirwain, - - -	1	Do.	1400	1400	1050	Do.
Melynicourt, - - -	1	Do.	648	648	503	Do.
Ennisgedyr, - - -	1	Do.	1352	1352	800	Do.
Caerfily, - - -	1	Do.	600	600	695	Do.
Cyfartha, - - -	3	Do.	6000	6000	7204	R. C.
Plymouth, - - -	1	Do.	2000	2000	2200	E. K.
Pendarron, - - -	2	Do.	4000	4000	4100	Do.
Dowlais, - - -	3	Do.	4100	5400	2800	Do.
Llanelly, - - -	1	Do.	1664	1664	1560	A. R.
Dovey, - - -	1	Mid Wales	200	200	150	E. K.
Ruabone, - - -	1	North Wales	1560	1560	1144	W. R.
Brymbo, - - -	1	Do.	884	Silent		Do.
Brymbo-gate, - - -	0	Do.	728	None		Do.
Penyvron, - - -	0	Do.	1498	Lead work		Do.
Pentrobn, - - -	0	Do.	1560	Do.		Do.
Carmarthen, - - -	1	W. Wales	1056	1056	290	E. K.
Level, - - -	1	Staffordshire	1560	1560	1391	T. S.
Brierly, - - -	1	Do.	1300	1300	1046½	Do.
Deepfield, - - -	2	Do.	2600	2600	2526	Do.
Bilfton, - - -	2	Do.	2340	2340	1429	Do.
Bradley, - - -	3	Do.	3640	3000	1920	Do.
Grave yard, - - -	1	Do.	1260	1336	213	Do.
Dudley port, - - -	1	Do.	1040	1040	869	Do.
Tipton, - - -	2	Do.	2080	2080	2203	Do.
Gospel Oak, - - -	1	Do.			1613	Do.
Neath Abbey, - - -	2	South Wales	3120	3120	1759	E. K.
	104		167,312½	133,965	108,993½	

SCOTCH FURNACES.

NAMES OF FURNACES.	No. of Furnaces.	Excise Return.	Supposed Quantity.	Exact Return.	From whom this information was received.
Carron, - - -	4	5200	5200	5616	T. E.
Wilfontown, - - -	2		2080	2080	A. H.
Muirkirk, - - -	2		3120	2878	T. E.
Clyde, - - -	3		3640	2216	Do.
Omoa, - - -	2		3000	2396	Do.
Devon, - - -	2				
Goatfield, (Charcoal) -	1		1600	300	E. K.
Bunawe, Do. - - -	1				
	17		18,640	16,086	
Manufactured in England and Wales,	104		133,965	108,993	
Grand Total, - - -	121		152,605	125,079	

Average Produce of each of the English and Welsh furnaces, 1048 Tons per Annum.
Ditto of each of the Scotch Furnaces, 946

The demand for iron articles of all kinds in this country not only continued unabated after the period of 1796, but kept increasing in a greater ratio than formerly; so that in the short space of five years, situations were occupied for nearly 50 additional furnaces, or additions made to established works of that extent. Betwixt 1801 and 1802, it was ascertained that the following new furnaces were either building or actually in blast, in England, Wales and Scotland.

In England and Wales.		Blowing.	Building.
Silverdale,	-	1	0
Snedhill,	-	2	0
Wibsey Moor,	-	1	0
Ketley,	-	1	0
Madely Wood	-	1	0
Burnet's Leafow,	-	1	0
Newcastle, Staffordshire	-	0	1
Cyfartha, South Wales,	-	1	0
Llanelly, Do.	-	1	0
Sirhowy, Do.	-	1	0
Beaufort, Do.	-	1	0
Plymouth,	-	1	0
Union,	-	0	1
Aberdare,	-	0	3
Tipton, near Bilston,	-	1	1
Bloomfield,	-	0	1
Longacres,	-	0	1
Wednesbury,	-	0	1
Staffordshire,	-	1	0
Coleford, Gloucestershire	-	1	0
Jackfield,	-	1	0
Old Park,	-	0	1
Donnington Wood,	-	0	1
Deepfield, Staffordshire,	-	1	0
Gornall Wood, Do.	-	1	0
Brierly Hill,	-	1	0
Bilston,	-	1	0
_____ , near Wolverhampton,	-	0	1
Dudley Wood,	-	0	5
Billingfly, Shropshire,	-	0	1
Newcastle upon Tyne,	-	0	2
		20	20

In Scotland.		Blowing.	Building.
Muirkirk,	-	1	0
Glenbuck,	-	1	0
Calder,	-	0	2
Markinch,	-	0	2
Shotts,	-	0	1
		2	5

Total of new Blast Furnaces 22 25

Blowing and building in Great Britain; the produce of which, supposing them all to have gone to work at the rate of 1000 tons per annum, from each furnace, would amount to, from 47 furnaces, 47,000 tons, Manufactured at, and previous } 121 furnaces, 125,079 to 1796, in

168 furnaces, 172,079 tons

The respective proportions of this astonishing produce in pig iron manufactured in England and Wales, and in Scotland, will stand thus:

	Furnaces.	Tons.
England and Wales, in 1796,	104	108,933
Ditto, since that period,	40	40,000
	144	148,933
Scotland, in 1796	17	16,086
Ditto, since that period		7,000
	24	23,086
Grand total in Britain,	168 making	172,079

In recapitulating the interesting facts which will result from a review of the gigantic progress of this manufactory, the regular progressive quantity made at a furnace is remarkable, or, which is the same, a diminution of the number of furnaces to perform the same quantity of labour.

Dudley represents, that in his day, 1620, there existed, in England and Wales alone, 300 blast furnaces, for the sole making of pig-iron, to each of these have been assigned the yearly produce of 250 tons.

At a period considerably after this, and before the use of pit-coal was found profitable in the furnace, 59 furnaces produced yearly 17,350 tons of charcoal iron, or each furnace average, 294

In 1788, there still existed in England 24 charcoal furnaces, which yearly manufactured 13,100 tons of metal, or from each furnace, on an average, 545

At the same period, in England and Wales, 53 blast furnaces, at which coke was used, manufactured yearly 48,100 tons, which upon an average was nearly, from each furnace, 907

The same year in Scotland, 8 furnaces produced 7000 tons of iron, or from each furnace, 875

In 1796, the number of furnaces in England and Wales amounted to 104, and yielded 108,993 tons of metal, which from each furnace was equal to 1048

The same year, in Scotland, 17 furnaces manufactured 16,086 tons of pig-iron, which is from each furnace, 946

These are by no means sufficient data to form an accurate opinion of the real progress or improvement of our blowing machinery in Britain. In the collection of furnaces in 1796, a number of charcoal blasts were included, which, from their general small produce, blowing only four, six, or nine months a year, reduces the average considerably on the whole. It may now be safely asserted, that the average produce in iron at pit-coal blast furnaces in England and Wales, is at melting iron works, 1200 tons

Do. at forge pig works, 2000

This bears a very striking contrast to the early exertions of the manufacturers in the sixteenth and seventeenth centuries, and exhibits a wonderful example of the general and rapid improvement of machinery in the last 50 years. With the improvements of machinery, the advancement of the manufacture of iron in general, and particularly of coke pig-iron, has kept equal pace. Nor have we sacrificed quality to quantity, but the reverse; for the melting pig-iron of our time is much more calculated for every variety of casting, than iron, equally saturated with the coaly principle, made with wood charcoal.

By comparing the value of a ton of pig-iron at different periods for the last 200 years, a pretty accurate opinion may be formed of the increased price of labour at iron works, and of the increased value of an object of universal utility in all our arts and manufactures.

About the year 1620, charcoal pig iron sold for	6l. per ton.
1788, ditto for melting,	8l.
1798, ditto	9l. 10s.
Coke pig iron, when first invented by Dudley,	} 4l.
was sold at	
In 1788, it sold for	5l. 10s.
1798, ditto	7l. 10s.
1802, melting iron was	8l. 10s.
And smooth-faced N ^o 1. sold at	9l. 10s.

One thing is here worthy of remark, that in a period of 170 years one ton of coke pig iron rose in value only 30s. i. e. betwixt 1620 and 1788; but that in the short period of 14 years following 1788, an advance of 4l. per ton took place. One thing only may be offered in extenuation of this immense rise, that part of it was owing to the misunderstanding that took place betwixt this country and some of the Baltic powers, which was no sooner adjusted than pig iron fell in price. The article still, however, maintains itself at 8l. 10s. per ton, being double the rise in point of value in fourteen years that took place in the one hundred and seventy preceding the commencement of that period.

To point out proper channels, whereby to account for the annual consumption of such an immense quantity of raw materials, would prove a satisfactory source of information. The endless detail into which the foundry trade has now branched itself, the almost universal fabrication which it embraces, and the extensive diffusion of the sites of manufactories themselves, preclude the possibility of obtaining this with strict accuracy. The following statement, however, will tend to throw some light upon the subject.

It is reckoned, that the bar iron forged in Britain manufactured annually from pig iron 40,000 tons of finished bars, which, at the rate of 35 cwt. of pigs for every ton of iron bar produced, will account for	Tons.
Consumed yearly in the erection of new furnaces, forges, machinery, &c.	70,000
Purchased by the board of ordnance in the state of cannons, mortars, carronades, shot, and shells, &c. on an average of 1794, 5, 6, -	10,935
Waste in melting from the pig, boring, &c.	1,300
Purchased by the navy board in the state of ball, &c.	12,235
India Company's annual supply in guns, shot, shells, carcasses, &c.	2,664
Waste melting, boring, &c.	5,000
Merchant guns, carronades, shot, &c. for arming trading vessels,	700
Waste in melting and boring,	10,000
Ballast for Merchantmen and India men,	1,000
	11,000
	5,000
	Tons 111,599

For the difference betwixt this and the total manufacture, recourse must be had to the large exportation to Ireland, and to the numerous and extensive casting foundries of London, Liverpool, Manchester, Birmingham, Warrington, Newcastle, Edinburgh, Glasgow, &c. none of which melt under 2000 tons yearly, and many of them from 4 to 5000 tons of melting pig iron.

We shall now leave this interesting subject with some ge-

neral observations upon the origin and progress of the pig iron manufacture, and its early use in the fabrication of castings.

It appears from Dudley, that towards the close of the reign of queen Elizabeth, blast furnaces had been constructed of size, and with machinery sufficient to produce upwards of two tons of charcoal iron per day. Such great products in iron were most probably confined to situations where there was abundance of water, and where water-wheels and bellows of a considerable magnitude were used. The more common modes of operation were confined to furnaces of an inferior size, which were supplied with air by means of hand-bellows, excited by cattle, or the labour of men. At the same period England enjoyed a considerable export trade, arising from her superior manufacture of iron guns, mortars, &c. As pit-coal had not been applied in any branch to the manufacturing of iron, it is probable, that these articles would be cast from the large blast furnaces; the flame of wood possessing but feeble effects compared to that of pit-coal, would render the application of the reverberating furnace, if then known, of no use in the casting of guns and mortars.

The non-application of pit-coal in every department of the melting foundry, would greatly retard the perfection, or even improvement of the art of moulding, and casting smaller and more general articles. The want of it, as the melting fuel in the blast furnace, was long severely felt by the general backward state of the art of moulding and casting in this country, and allowed other nations with fewer advantages to get the start of us. It is highly probable, that long before the period formerly alluded to, the application of pit-coal had been speculated upon, either as an auxiliary, or as a substitute in every branch of the iron business. Its well known inflammability and tendency to form a cinder, and the general decay of wood, would furnish ample grounds for what, to many at the time, would be considered as idle and visionary speculations. The advantages arising from the trade, as it was then situated, had been rigidly ascertained, and fully appreciated by the established manufacturers. The business, in point of extent, seemed only limited by the supply of wood. New erections, for want of a proper supply of materials, became impracticable; those already engaged were more anxious to preserve their supply, however much circumscribed, than listen to innovation, which, by substituting pit-coal for the charcoal of wood, would likely give to the speculatist a great superiority in the market. It is also highly probable, that many of the iron works then established were at a considerable distance from pit-coal, the general introduction of which would prove fatal to their interests.

In this view of the subject, the adventurer with capital had every thing to hope, the established manufacturer every thing to fear, by change. Under these circumstances, the discovery, or rather the assertion of the practicability of making iron with pit-coal, was announced by Simon Sturtevant, esq. in the year 1612, who, upon application, was favoured with a patent from king James, for the exclusive manufacture of iron with pit-coal, in all its branches, for the long period of thirty-one years. In return, the said Simon Sturtevant bound himself to publish a faithful account of his discoveries, which afterwards appeared in quarto, under the title of his "Metallica." It is uncertain to what causes his failure was at the time attributed, but in the execution of his discoveries upon a large scale, he had found difficulties amounting to utter impracticability; for in the year following, he was obliged to make a surrender of his letters of monopoly.

The second adventurer in this unexplored path we find to have been John Ravenfon, esq. who, like Sturtevant, was successful in obtaining a patent for the new manufacture; but, like him also, was inadequate to the completion of it upon a profitable scale. Ravenfon was also enjoined to publish his discoveries under the title of his "*Metallica*," which was printed for Thomas Thorp, anno 1613. Several other adventurers stepped forth, all of whom had the mortification of resigning their patents, without having contributed to the success of their arduous undertaking.

In 1619, Dudley obtained his patent, and declared, that although he made only at the rate of three tons per week, he made it with profit.

This discovery was perfected at his father's works at Pensent, in Worcester-shire. This gentleman's success in the various manufactures of iron with pit-coal, had united not only all the proprietors in the charcoal iron trade, but many new adventurers, who wished to share in the emoluments, or to acquire part of the fame of the new discovery. Their interest was sufficient to limit the duration of Dudley's patent from 31 to 14 years. During the greatest part of this period, according to his own statement, he continued to make pig and bar iron, and various castings; all of which he sold much lower than the charcoal manufacturers. In the article of castings he must have had greatly the start of the charcoal foundries, as the quality of melting coke pig-iron is far superior to that of charcoal, particularly that made in this country for the general purposes of casting. Nor was the superior genius of Dudley always an object of passive indifference in the narrow estimation of the new adventurers and the established manufacturers. The envy occasioned by his uncommon success, produced at last a spirit of combination, which terminated in a hostile attack upon his devoted works. His improved bellows, furnace, forge, &c. all fell a prey to a lawless banditti, betwixt whom and its furious leaders no shades of distinction were visible, but those of avarice, ignorance, and the most contemptible prejudice.

To evade the mode of operation discovered by Dudley, or to introduce the making of coke pig-iron with greater advantages, a new plan was adopted by captain Buck, major Wildman, and others, in the forest of Dean, where they erected large air-furnaces, into which they introduced clay pots resembling those used at glass houses, filled with the necessary preparations of ore and charcoal. The furnaces were heated with the flame of pit-coal; and it is probable, that by tapping the pots below, it was expected that the separated metal would flow out. This rude process of assaying on a large scale, was in the end found utterly impracticable; the heat was inadequate to perfect separation; the pots cracked; and, in a short time, the process was abandoned altogether.

The misfortunes which befel the sanguine, but unfortunate Dudley, were an irreparable loss to the perfection of the coke pig process. The hostile rivalships he had to encounter in consequence of the new ground he had occupied as a manufacturer, together with a zealous attachment to the royal cause during the civil war which followed his discovery, completely prevented his improvements from attaining a pitch of permanency and general utility. The refusal of a new patent after the restoration, prevented him from again entering the laborious paths of discovery and improvement, although it appears, that his former application to the perfecting of this branch of manufacture had not been unsuccessful, for in place of three tons of coke pig weekly, in his petition praying for a renewal of his ancient rights, he states, that he could now manufacture seven tons by means of a large furnace, and an improved bellows.

No greater pitch of improvement took place for nearly one hundred years after this period. The practicability of the manufacture was discovered; but the mode of obtaining quantity, to ensure in general a profitable return, depended upon other circumstances than the proportioning of the raw materials together. Had machinery received the same improvements in the time of Dudley, it is more than probable that the rapid progress of the coke pig trade would have dated its origin from that period. But this great era in the history of our manufactures was reserved for a much later date; and in the improvements of the steam engine, we see new life and existence conferred upon every species of art that can be made subject to motion or mechanical control.

BLAST Furnace Works, are large and expensive buildings for the manufacturing of pig iron. An erection upon the smallest scale must consist of a furnace, casting-house, bridge-house, and blowing engine. The latter is sometimes, though seldom, worked by means of a water wheel. The most universal mode of blowing is by means of a steam engine. See *BLOWING Machine*.

There is no general plan laid down for building a blast furnace work. The singular situation which should be occupied, to insure every convenience, renders this dependent upon the nature of the ground.

It is always reckoned a great advantage to place the blowing machine at as short a distance as possible from the furnace or furnaces, that the air may have the least possible travel in the conducting pipes. When this cannot be conveniently effected, the diameter of the pipes ought to be made sufficiently large to admit of the blast passing without any material friction.

The usual appendages to blast furnaces are mines of coal, iron-stone, and lime-stone. And these form no inconsiderable portion of the whole expence.

In situations where blast furnace building materials are at a moderate price, and when no uncommon difficulty occurs in the progress of the general operations, 15000*l.* of sunk capital may be deemed requisite for one furnace; and for every furnace after this, 10,000*l.* may be added.

This great capital for many years kept the trade in the hands of a few; but of late, since capitalists have become more common, the number and extent of the blast furnace erections have become truly astonishing.

The following descriptions of plates illustrative of the plan and arrangement of blast furnace works will convey a tolerable idea of the nature of these buildings.

Plate XI. Blast Furnace Works, represents the ground plan of an entire fabric, consisting of

A steam-engine for blowing two furnaces.

2 Blast furnaces.

2 Bridge-houses.

1 Casting house.

1 Boiler-house.

2 Boilers.

1 Chimney for boiler flues.

A, Engine-house, 40 feet long, 18 feet wide.

B, Pedestal for steam cylinder: 7 feet square at base, and 4 feet at top.

C, Pedestal for blowing, or air cylinder. Base 10 feet square, top 7 feet square. These are generally built of solid hewn stone, and bedded with the greatest accuracy. From centre to centre of the two pedestals is 24 feet, which is also the distance betwixt centre and centre of the steam and air cylinders.

D, Door or opening through the lever wall. This wall at bottom is built 5½ feet thick, but is occasionally reduced

in point of thickness to $3\frac{1}{2}$ feet at top, as may be seen at the corresponding letter in the section.

F, Door or opening from the engine into the boiler-house. An opening above this serves to conduct the steam pipe from the boiler to the steam apparatus at the cylinder.

E, Door or opening for carrying through the blast pipes from the top and bottom of the air cylinder to the water receiver below.

G, The boiler-house, 40 feet by 30 within the walls. As this is excavated from the solid hill to the depth of 30 feet, it is requisite to have the walls uncommonly strong. Those in the plan are 6 feet thick at bottom, and are reduced at three different heights in thickness, as represented by the interior lines.

H H, Two boiler seats for boilers, 18 feet long, $9\frac{1}{2}$ feet high, and 7 feet wide.

I I, Fire-places, 6 feet square.

K K, Dead-plates before the bars or grates.

L L, Openings where the furnace doors are hung.

M M, Semi-circular openings formed beyond the dotted line, or termination of the boiler, in which the flame from the grates rises to enter the iron flue or tube, which is placed in the centre of the boiler.

N, Chimney, $2\frac{1}{2}$ feet square within, and 50 feet in total height; from the bottom of the flue 42, and 8 feet from the foundation.

O O, Coal pits for containing small coals for the engine's supply. These are 8 feet by 6 at bottom, and widen gradually as they approach the surface of the coke yard. The coals are there emptied from the cart into these receivers, and the engine-man easily supplies his wants from the small openings which communicate with O into the boiler-house.

P P, Bridge-houses for containing cokes, iron-stone, and lime-stone, for filling the furnace. Measurement within 42 by 40 feet.

Q Q, Doors or entrances from the coke yard into the bridge-houses.

R R, Openings from the bridge-house, which is here connected with the furnace, by means of an arch and parapet walls. This is more fully seen in the elevation section P. Along this bridge the materials are carried or wheeled into the mouth of the furnace.

S S, Two blast furnaces, 34 feet square in the base.

T, Casting-house 102 feet long by 48 in width, from the front wall or arch of the furnace, or 88 feet wide from the front wall of the engine and bridge-houses, and 24 feet high in the side walls.

W, Water receiver for receiving and equalizing the column of blast. Length 40 feet, and breadth 18 feet.

V, The space in which the equivalent column of water rises, 3 feet wide. The exterior line denotes the inverted iron chest; the interior lines, the different basements formed by the stone work laid upon the chest to prevent it from rising when the engine is at work.

Y, Termination of the blast conduct pipes from the air cylinder into the iron receiver, 2 feet 6 inches diameter.

Z, Position for the horizontal range of pipes to branch off, which are meant to convey the blast to the opposite tuyeres, *a a*, betwixt the back wall of the furnace, and the bridge-house.

bb, The two tuyere sides next the water pressure. From Y proceeds a straight pipe along the centre line *b*, for conveying the blast to that side of the furnace.

c c, Front arches, under which the furnace workmen perform all the labour of tapping, casting, and cleaning the furnace.

dd, The spaces inclosed within these dotted lines are called pig beds. They are kept constantly filled with sand, and in them the operation of moulding and running the pig metal is constantly performed.

Plate XII. Blast Furnace works.

Elevated section of the ground plan, Plate XI. through N F B D C E and X.

A, Inside of the blast engine-house.

B, Steam cylinder pedestal.

C, Blowing or air cylinder pedestal. Both of these are built upon 4 or 6 inch planking, laid upon strong logs, which are again supported upon the solid stone buildings, *a a*, running from the lower wall along the side wall of the engine-house, to the wall perpendicular to E. The binding down bolts that pass through the flanges of the cylinders are strongly keyed upon the under side of the logs, and are at all times easily accessible.

D, The lever wall and opening of communication betwixt the steam and blowing end of the engine-house.

F, Door or opening into the casting house and water regulators.

E, Door to the boiler house.

G, The boiler-house.

H, One of the boiler seats.

I, One of the boilers, 18 feet long, by $9\frac{1}{2}$ wide, by 7 high.

K, Manhole door for entering the boiler.

L, Thorough arch in the foundation of the chimæy.

M, Throat, or opening into the chimney, for the passage of the flame and smoke.

O, Coal pit for containing fuel for the engine.

P, Arched passage of communication betwixt the bridge-house and furnace mouth. The opening in the bridge-house is more distinctly seen at R, Plate XI.

S, Side view of one of the blast furnaces, as connected with its corresponding bridge-house.

W, Water vault, or cistern, for receiving the inverted chest. In rocky foundations this is cut out of the rock, but in soft ground the excavation is made and lined with well jointed mason work, puddled behind with clay to prevent the loss of water.

T, Casting-house and roof.

b, The tuyere arch.

c, The sow, or lintel of cast-iron, 12 inches square.

d, The orifice at which the blast enters, called the tuyere.

e, Spring beams of the engine house, A. These are composed of two logs 14 inches square. The main gudgeon, seat, and beam rest upon these.

f, Stay logs for the steam cylinder.

g, Ditto, for the blowing cylinder.

Description of Plate XIII. Blast Furnace Works.

Cross section and elevation of Plate XI. through S Y S.

S S, Section of two blast furnaces, and their situation as connected with the blowing apparatus.

Y, The branch pipe for communicating the air to the inside tuyeres of the furnace. This pipe has another branch of communication behind, which connects it to the blast pipes which descend from the blowing cylinder at A, and to the double column of pipes which are carried round behind the furnace to the opposite tuyeres.

C C, View of the pipes which convey the air to the opposite tuyeres, where double blasts are in use.

D, Front wall of engine and bridge-houses.

X, Iron chest inverted in the water receiver, and connected with the blast pipes.

V V, Opening all round for the water to ascend, as it becomes expressed from the chest by the impelling force of the blast.

O, Logs on which the chest is inverted, to preserve it from the floor of the water receiver, from 12 inches to 18 of space.

Description of *Plate XIV. Blast Furnace Works.*

Ground plan of an extensive blast furnace foundry, consisting of four furnaces and two blast engines. The peculiar construction of this plan is, that only one furnace may be erected at a time, and afterwards the whole number; still preserving that regularity and uniformity of design which will at any time make the blowing machinery of one part subservient to the whole, in case of accidents, stoppages for repairs, &c.

A, Engine-house, with cylinder, pedestals, lever wall, openings, &c.

B B, Two boiler-seats and boilers.

CC, Water regulators for the blast, which conveniently communicates, by means of pipes, with the blowing cylinders, placed upon the pedestals behind A, I.

DD, &c. Centre line of the whole blast pipes. This extensive column may be so arranged, as to enable the furnaces to be blown each with two tuyeres; and the blast of one engine made to pass through the whole. The general communication is effected by carrying the chief column either behind the furnaces, or, as in the plate, through the main pillar of the furnace, by means of an arched opening 3 feet wide.

E, Ground plan of the hearth, squares, and pillars of four blast furnaces.

FFFF, Bridge-houses for materials, and filling or charging the furnace.

GGGG, Openings into the furnace top.

H, Casting-house.

I, Second blast-engine, upon the same plan as A. Each of these two engines ought to be calculated to blow two furnaces, and occasionally, when any thing goes wrong with one, the blast of the other could be easily distributed for a time among all the furnaces.

BLASTED, in *Antiquity*, something struck with a *blast*.

Among the Romans, places blasted with lightning were to be consecrated to Jupiter, under the name of *bidentalia*, and *putealia*. It was also a ceremonial of religion to burn blasted bodies in the fire.

BLASTING of *stones*, in *Agriculture*, the operation of tearing asunder large stones or rocks, which are in the way of the plough or other instruments employed in breaking up ground, by means of gun-powder. The method of performing this business is by boring a large hole, eight, ten, twelve, or more inches deep, according to the nature and size of the stone or rock to be blasted, by means of a chisel for the purpose, and then introducing a sufficient quantity of gun-powder, and afterwards carefully ramming the hole up with small fragments of stone or other solid materials, only leaving a very small aperture, by placing a steel pricker of sufficient length and suitable dimensions, with a handle at

the top, at first into the powder, and frequently turning it round while the hole is ramming up. After the hole is quite filled, by forcing the hard materials in with a proper instrument, the pricker is withdrawn, and the aperture left by it filled to the top with gun-powder, and then a match of tow, straw, or other light inflammable material laid to it, and set on fire.

It is observed by Mr. Headrick, in the second volume of "Communications to the Board of Agriculture," that in order to perform this operation properly some experience is necessary, and that a skilful workman can frequently rend stones into three equal pieces, without causing the fragments to fly about. This, he says, depends upon the depth and position of the bore. It is also remarked, that a small portion of quick-lime, in fine powder, is found to increase the force, and consequently to diminish the expence of blasting stones. On these grounds the following is offered as a substitute for gun-powder, which is now become very expensive, though, as is freely confessed, without any experience of its effects. Supposing *fig. 1, Plate III. (Agriculture)* to be a large stone to be blasted or rent; *ab*, a bore sent down into it in the usual manner. This bore being then well cleaned out and dried, is to be filled from *b* to *c* with the purest quicklime, or such as swells most in slaking. That it may be perfectly quick it should be taken red hot from the kiln, or the small furnace where it has been burnt; being then rammed in hard with the jumper or punch *a c*, the upper part of the bore is to be crammed with rotten rock in the ordinary way. The pricker being removed leaves the aperture at *b*, *a b*, a small pipe of copper, of less diameter than the needle or pricker, having an orifice about the dimensions of the straw, used to convey the fire down to the gunpowder, with a funnel *d* to receive water, is introduced into the aperture. Perhaps a straw or small reed stuck in the lower part of the funnel, among tallow or bees wax, might serve the purpose of a copper pipe. Things being thus prepared, pour water into the funnel *d*; and if the pipe be not too high, so as to prevent the air from escaping from the aperture, left by the pricker, it will descend and cause the lime to flake in the bore *c b*. Every one knows how irresistibly the purest quicklime attracts water, and with what prodigious force it expands in slaking into three or four times its former bulk. From these data it is therefore inferred, that the slaking of lime, in such circumstances, would burst or rend the stone *f* in pieces; but the success of such an experiment, it is observed, must depend entirely upon using lime of the utmost purity, and having it very hot, and perfectly caustic when it is put in.

It is further remarked that if the bore *c b* were filled with water, and the aperture afterwards rammed up, the water being made to freeze by cold, would rend the stone; for when water passes from a fluid to a solid form, it expands with irresistible force, though frost cannot be depended upon in this climate.

Bleaching

BLEACHING. The art of bleaching consists in removing the coloured matters intermixed with vegetable and animal substances in their natural state, or such as they have subsequently imbibed by accident, or some artificial process. Edward Hufley Delaval, esq. F.R.S. has shewn, by a number of accurate experiments on the cause of the permanent colours of opaque bodies, published in the second volume of the second edition of the *Memoirs of the Literary and Philosophical Society of Manchester*, "that when the colouring matter of plants is extracted from them, the solid fibrous parts, thus divested of their covering, display that whiteness which is their distinguishing character. White paper and linen are formed of such fibrous vegetable matter, which is bleached by dissolving and detaching the heterogeneous coloured particles." He further observes, "it appears that the earth, which forms the solid substance of plants, is white; that it is separable from the colouring matter by several means; that whenever it is either pure and unmixed, or diffused through transparent colourless media, it exhibits its whiteness, and is the only vegetable matter which is endued with a reflective power; that the colours of vegetables are produced by the light reflected from this white matter, and transmitted from thence through the coloured coat or covering, which is formed on its surface by the colouring particles; that whenever the colouring matter is either discharged or divided by solution into particles, too minute to exhibit any colour, the solid earthy substance is exposed to view, and displays that whiteness, which, as before noticed, is its distinguishing character."

He states that in all those animal matters which do exhibit colours, the colouring particles are endued with the same properties, and are regulated by the same laws, which prevail in vegetable substances.

A reference to the original paper can only do justice to the observations of this excellent philosopher, confirmed by numberless experiments; but what is already said will be sufficient to give an idea of the nature of the process of

bleaching, and that it depends on the removal of the matter interposed betwixt the air and this white substance.

The national importance of bleaching is so great, that it comprehends nearly the whole of the cotton and linen manufacture, and goes to an extent beyond most other arts.

Its operation in these branches may be considered under two points; viz. 1st, the separation of extraneous substances from linen and cotton, which is effected by steeping, fermentation, or weak alkaline leys; 2d, the separation of the constituent or inherent colouring matters of those substances, which is effected by different modes, and by various modifications of each method, as exposure to the air, light, the use of alkaline leys, soap, oxygenated muriatic acid, combinations of oxygenated muriatic acid with other matters, sulphuric acid, hepar sulphuris, &c.

To impress upon the mind the nature of the bleaching business, it will be proper first to describe the vessels used in the sundry operations of steeping, boiling, bucking, washing, souring, &c. then proceed to shew the management of each process, with some observations on its effects; and, lastly, how to make or procure the articles necessarily employed in this art, and the method of ascertaining the qualities of each, adding some observations on the theory of the operations.

BLEACHING of goods, particularly cotton manufactures.

1st, *On Steeping.*

The vessels generally used in bleaching are made of such wood as will not communicate any colour to the liquors they are to contain, and therefore deal or fir wood is preferable to most others. The vessels employed for steeping the goods when received from the loom are usually of the form A, *fig. 1. Plate I. Bleaching.* The goods when received from the weaver contain not only the natural colouring matter of the cotton, which is of an oily nature, and which prevents the cloth from easily imbibing water, but also a substance called *sowins*, being a paste made of flour and water, used during the weaving, and applied with brushes upon the warp, in order to give a firmness to the threads by glueing or

or palling together the loose fibres of the threads, and thus allowing them to pass more freely through the reed and harness. To remove this substance, and to open the fibres of the cotton, so as to give full effect to the subsequent operations, it is proper to steep the goods in a vessel of the above form in lukewarm water, till a gentle fermentation takes place, which will usually be effected in 24 hours. The cloth should then be taken out, and well washed in a current of clear water, which will thus separate a considerable quantity of filth without the expence of using alkaline leys; and the cloth is then ready to be boiled or bucked as may be preferred by the bleacher.

2d, On Boiling.

For boiling, a copper vessel is to be preferred, and the goods prepared, as above mentioned, by steeping and washing, are put into the vessel containing hot water only, or warm alkaline ley; a winch is placed over the vessel, and the piece goods attached to the ends of each other, are, when put in motion by the handle of the winch, dragged or rolled over it till the whole are passed; the winch is then turned with a retrograde motion, and the cloth gradually thus returned back, in order that every part of each piece may be thoroughly impregnated with the liquor, which is raised to and kept at a boiling heat, as long as it appears to extract any colouring matter from the cloth; the goods are then taken out and well washed in water.

Fig. 1. Plate IV. shews a section of the boiling pan A, of copper, set in brickwork B; the winch C, with its handle D; E, uprights of wood, on which the winch turns; F, a cock to empty the pan; G, the fire-place; H, the ash-hole.

The use of this process depends upon the properties which alkaline salts have of uniting with the oily and resinous matters which are either attached to or are a constituent part of vegetable fibres, and which contain their colouring particles, forming with them a saponaceous matter, soluble in water, and by that means easily extricated from the cloth.

3d, On Bucking.

As this is one of the most general operations in bleaching, it will be necessary to describe it more particularly. *Fig. 1. Plate I.* under the word *bucking*, shews at A the form of the bucking tub or kier, in which the goods are to be laid; B is an iron boiler, in which the alkaline salts, as pot-ashes or pearl-ashes, are to be dissolved in boiling water; C is the fire-place, in which a fire is constantly kept up; D is the ash-hole; E, a cock through which the boiling ley is let out upon the goods closely placed together in the bucking tub, A. A sufficient quantity of boiling ley is let into the bucking tub, till all the goods in the tub are thoroughly impregnated with it; the ley liquor is then allowed to pass by a cock at H into an iron vessel placed in the ground at F, and from thence raised by the pump G into the iron boiler B, and thence returned hot again upon the cloth. This operation is continued for several hours, till the ley, by the separation of the colouring matter in the cloth, acquires a colour almost black, a very offensive smell, and nearly the consistence of molasses or treacle. The cloth is then taken out, well washed from its impurities, and, in the old mode of bleaching, it is then laid upon the ground to be whitened by exposure to the atmosphere, but, in the new mode of bleaching, is submitted to the action of the oxygenated muriatic acid, to procure a similar whiteness. It may be proper here to notice, that the old and new methods of bleaching are yet much the same as formerly, only in the substitution of the use of the oxygenated muriatic acid in those parts of the process, where a long exposure to the atmosphere was formerly employed after the alkaline leys.

The operation of bucking acts on a similar principle to that of boiling, but in a much more forcible manner, as a greater quantity of ashes is added in proportion to the water made use of, and more heat is received and retained in the large bulk of cloth placed in the bucking tub, which expands the fibres of the cotton, and admits the more powerful action of the alkali, as is easily demonstrated by observing the very dark colour of the alkaline leys which have been used in bucking, in comparison with those which have been employed in boiling goods. To those persons who wish for a full and minute account of the absorption and power of heat, we recommend a perusal of count Rumford's interesting essays on the subject of heat.

The black alkaline ley which remains after bucking should be preserved, as it will answer, after evaporating and calcining, as hereafter mentioned, to form again fresh alkaline salts of good quality. With a view to preserve as much of the ley as possible, it will be advisable to wring it out into a tub from the cloth or yarn, after it is bucked, by the method shewn in *Plate IV. fig. 3.* where R R are two strong posts, fixed firm in the ground, S T two wringing hooks, upon which the cloth U is twisted, to force out the liquor, by W, a winch handle, which turns the hook round on the post R. The two hooks are kept at a proper distance from each other, one by a collar at X, the other by an iron pin at Y, which runs through a hole in the square part belonging to the hook T, which square has several holes in it to bring this hook nearer to the hook S when required.

4th, Souring.

This process consists in immersing, for the space of twelve hours, or more, the yarn or cotton in a mixture of water and sulphuric acid (vitriolic acid), well incorporated; the proper strength of which mixture is about the acidity of lemon juice, and is usually directed by the taste. The sour kettle should be made of lead, of a form which can be heated; the heat of the liquor should not be greater than the hand can bear with ease. This sour kettle should be half sunk within the ground, as shewn in *Plate IV. fig. 2.* where M is a section of the souring vessel; N, the level of the ground; O, the brickwork; P, the fire-place, which is a half circle, or arch, without any grate; I L I, a space filled with dry ashes, betwixt the lower part of the sour vessel and the brick-work, in order to preserve the heat of the liquor in that part of the vessel below the surface of the ground; K, a brick hearth, on which part of the fire is made; L, a cast iron plate, bending in the form of the sour kettle, which is intended to prevent the fire placed on the floor at P K, from acting upon the lead of the sour vessel; Q, the space betwixt the vessel and brick-work, through which the smoke goes to the chimney.

The construction of this apparatus is upon the same principle as the warm vats made use of by the blue dyers, the intent not being to make the liquor boil, but to keep it at a degree of heat which the hand can long and easily bear. There are no grate or bars necessary in this fire-place, as the coals will burn with sufficient rapidity without them.

The goods may be put into this acid liquor either in a wet or dry state. The best plan is to immerse the goods in the evening in the acid liquor cold, let them remain covered with it all night, then in the morning make a fire and bring the liquor to a blood heat, in which state having a winch over the vessel, similar to that represented at C, *fig. 1.* give the goods a few turns over it, that every part of them may be exposed to the action of the liquor. The goods may then be lapped round the winch to drain a little, to prevent an unnecessary waste of the acid liquor, and afterwards carried to the wash-wheel, or river, to be well washed from

the acid, so that the cloth may be perfectly tasteless to the tongue. It is a remarkable circumstance, that cloth may remain immersed a very considerable time in a strong acid liquor without rotting, but that if exposed to the air or heat of a stove, if a very small portion of acidity remains in the cloth, it becomes so concentrated by heat, as to damage the cloth immediately; therefore too much attention cannot be paid to this point.

The use of the acid liquor above-mentioned is to dissolve any earthy or metallic matters inherent in the cloth, or which may have been communicated to it accidentally, or which it may have derived from the impurity of the alkaline salts used in the bucking or boiling.

A considerable quantity of the acid liquor may be preserved by passing the goods which have been soured through a tub of clean cold water, previous to washing them, and replenishing the sour kettle with this acidulated liquor, rather than water only.

5th, *Washing.*

After every operation in which acids or alkaline substances are used in bleaching, it is necessary that the goods should be well washed in clear water; it is therefore of the greatest consequence that the water of a bleach ground should be pure, and in considerable quantities, such, for instance, as is perfectly transparent, will not curdle with soap, nor yield any degree of blackness with powdered gall nuts, or, which is a more accurate test, with a tincture of galls by infusion in spirits of wine.

Various methods have been invented for the purpose of washing out the impurities of the articles to be bleached; such as cleansing them in a large current of water by shaking them with the hand in the stream, beating them on blocks of wood with a flat paddle, or hand brush, beating them on a large flat stone with long wooden levers, flatted underneath, passing them over winches placed above vessels of water, or rivers, as *fig. 1. and 3. Plate II.* passing them betwixt plain or fluted rollers, as *fig. 5. and 6.* putting them under fulling mills, or fulling stocks, as *fig. 7. or* within wash-wheels, as *fig. 1. and 2.* and by many other modes, few of which are equal, and perhaps none superior, to those of which engravings are here given, for doing the business simply, effectually, and with ease to the workmen; the latter point of which is of consequence to be attended to, as it will be universally found in every mechanical employment, that if the least additional labour or care is required from the workmen, however great the effects produced, prejudice or indolence will prevent their doing justice to the invention. Under these circumstances, the wash-wheel represented in *Plate II. fig. 1, 3, 4,* is the best machine for general use, and the least liable to occasion damage to the goods. The front of the wash-wheel represented at *A, fig. 1.* is supposed to be eight feet diameter, exclusive of the buckets *B,* shewn by dotted lines on its periphery, which give it motion from the water falling into them. This wheel is divided within into four parts or quarters, by the strong arms projecting from the shafts *D,* to the outer circle; in each of these separate quarters or boxes, represented by dotted lines, one or more pieces of goods which require washing, are put loosely folded together through one of the holes *C,* of 14 inches diameter.

Fig. 2. shews the back part of the said wash-wheel, which is made of solid planks, excepting a grate of slender iron bars marked *R,* which encircles the wheel underneath the separation boards or bottoms of the buckets; the use of this grating is to admit within the wheel a current of clear water from the pipe *Q.* When an equal number of piece goods have been introduced into each of the four divisions of the wheel by the holes, *C,* &c. above mentioned, a current of clear water

is permitted to run through a cock from the pipe *Q,* against the grating *R,* which allows it to flow freely through into the boxes, or those parts of the wheel which contain the goods; a valve is then opened from the trough *P,* communicating with a large reservoir or stream of water, a sufficient quantity of which is let into the outside buckets from the valve, to give the proper motion to the wash-wheel containing the goods. In every revolution of the wheel, the goods in each quarter of it are thrown twice, by the simple motion of the wheel, with great force against the arms which form the four divisions of it; viz. once in going down, and once in rising up. The ear can distinguish by the firmness of the sound when the wheel moves with proper velocity; and a greater or less quantity of water is allowed to act upon the buckets till that is attained, which usually is when the wheel makes 15 or 16 revolutions in a minute. During the whole time the wheel is in motion, the stream of clear water from the pipe *Q* flows upon the goods within the wheel in every direction; and the dirty water, produced from thus washing the goods, runs out of the wheels from a number of holes bored through the wood-work near the axle, and a few made in the front near the outer circle of the wheel. *Fig. 4.* shews an end view of the wash-wheel, about thirty inches wide, with the manner that the bucket-work is made.

It has been found to answer equally well to make use of a greater number of wash-wheels of a smaller size, as six feet diameter and two feet wide, of which several may be put in motion at once by a large water-wheel, horses, or a steam engine.

The goods, when taken out of the wash-wheel, are to be unfolded, and taken to the river to be streamed, or may be washed from any impurities which may remain in the folds by means of a winch *N,* *fig. 1. and 3. Plate II.* where six pieces of cloth are represented in the action of washing in a large wooden back divided into six partitions, to prevent the pieces of goods entangling with each other. *Fig. 1.* is a side view of the operation, where the dotted lines represent the partitions which separate the goods; *I,* a trundle wheel, which being put in motion by the cogs, *H,* of the wash-wheel, turns the winch on its axle, which winch may at any time be detached from it by the handle *M* drawing the catch *K* from the hook, as is shewn in the top view *fig. 3.* where also is explained, at the letters *OOOOO,* the manner in which each piece of goods is kept in its proper place on the winch, by the partitions above mentioned, and by angular slips of wood nailed to the back and partitions.

To assist the drying of the goods after washing, they are usually passed betwixt two small rollers, commonly called squeezers, represented at *fig. 5,* where *G* is a solid wooden frame, containing two wooden rollers, each from 10 to 16 inches long, on an iron axis, which rollers receive a proper pressure by means of the two screws *T* acting on an iron bar *V,* which rests on the two ends of the axis of the top roller, as shewn by the dotted lines. In proportion as the screws press the iron bar upon the axle of the top roller, it brings that roller closer in contact with the bottom roller, and occasions more water to be pressed out of the cloth, which is passed betwixt them loosely drawn together, something like a rope, and the goods therefore require less time in the subsequent drying. In this plate the squeezers are connected with the wash-wheel above mentioned by a square iron socket, which, as is shewn at *F,* slides occasionally upon the squares of both axes. *Fig. 4.* shews at *S* the buckets of the wash-wheel, on which the water falls to give it motion; *H,* the cogs round its axle, which work the trundle wheel *I.*

Fig. 6. Plate II. shews two views of another machine used for cleansing cotton goods, consisting of two fluted or

grooved rollers, in the section of which *a* represents the sills, or bottom timbers; *bb*, the two supports or side pieces; *c*, one of the upright pieces in which the axles of the rollers are placed; *dd*, the two cross pieces to secure the frame work below; *ee*, the two rollers with grooved channels which fit to each other; *h*, one of the levers, which, from a point *i*, shewn by dotted lines, presses on the round end of the axle of the top roller, more or less, according as the weight *k* is placed on the lever further from or nearer to the axis of the roller.

In the geometrical elevation of the same machine, *ee* shews a front view of the two rollers; *fg*, the winch to turn it, with a hollow wood handle upon the iron work; *l*, the axis of the upper roller projecting beyond the side timber, so as to admit one of the levers *h* above mentioned to press upon it.

The wet goods, by being passed backwards and forwards through these fluted rollers, which are constructed at a much less expence than wash-wheels, are considerably cleansed, but not so perfectly as by the wash-wheels above mentioned.

Fig. 7. Plate II. explains another mode of cleansing goods, and is applicable to cotton, linen, or woollen goods, but more generally to the two last, as, without great care in its management, it is very apt to tear or damage cotton goods. This machinery is usually termed falling stocks, or falling hammers. *Nº 1.* is the axle of the water-wheel, in which are fixed tappets at 2, to raise alternately the levers 3, 4, furnished with large wooden mallets or hammer heads 6, 8, channelled at the lower part as at 8. These lever hammers or fallers, work from a pin fixed in the upright at 7; 9 is a strong piece of timber hollowed out at 10, to receive the goods to be cleansed; 11, a piece of timber fixed a-flant to keep the fallers in their proper place, and direct their motion; 12, a chain fastened to each faller, serving by means of the hook 13, to suspend the faller whilst the goods are put in or taken out of the cavity 10.

When the goods to be cleansed are placed in a loose bundle in this cavity, the hammers are let down upon them, and put in motion alternately by the tappets 2, in rotation, which raise the levers to a certain height, and then quitting them, the hammer heads by their great weight, fall with great force on the goods in the cavity below them; and a current of clear water being admitted upon the goods from a cock above them, the dirty water runs out at a hole in the bottom of the cavity. The falling of the hammers gives a slow circular motion to the goods in the cavity, so as to expose the several parts in rotation to the action of the hammers.

Having noticed the vessels made use of in bleaching, and the general nature of the several operations, we shall now proceed to mention the origin of the several improvements made in this art, and their application to practice.

Under the operation of steeping, we have shewn the method of removing the colouring matters not natural to the vegetable, but acquired in the manufacture, and which may probably be best done by water alone, though sometimes some of the old leys, which have been previously used to other cloth, are employed to this purpose. After the steeping, and indeed after every application of bleaching agents, it should be laid down as a general rule, that the cloth or goods be carefully washed in cold water.

In the old method of bleaching, alkalies, such as pearl or pot-ashes, were, after steeping, applied by bucking or boiling, with alternate exposure to the atmosphere.

Alkalies acting so important a part, it is necessary to describe the bleachers' mode of using them, which consists in dissolving them in clean water, and thus forming what is

termed an ash-ley. To which the more intelligent bleacher, if he does not make use of American pot-ash, or that of a similar quality, adds $\frac{1}{2}$ of quicklime, whereby the ashes are rendered caustic, and their power materially augmented. But in order that no inconvenience may arise from causticity, after mixture, the whole is allowed to settle, and from the pure liquor thereof the work is afterwards supplied; the bleacher, in drawing it off, reducing it by the addition of water to the different strengths which the goods may require.

The ley being prepared, the bleacher proceeds to apply it to the cloth by bucking or by boiling.

In bucking, the alkaline ley is put into the boiler before described, near to and below which is the wooden vessel called a kier, in which the goods are loosely and regularly arranged. After this, a fire is put under the boiler, and beginning whilst the ley is yet cold, it is made to circulate through the cloth in the kier, from which it runs into the iron vessel placed in the ground, from this it is pumped up into the boiler, and again returned upon the cloth in the kier; and this circulation is maintained, and the heat at the same time increased, until the ley be so far concentrated by evaporation, as at last to remain almost wholly in the cloth. This is generally the operation of a day, and the cloth is allowed afterwards to remain thus impregnated with the concentrated ley until next morning.

In boiling in alkaline leys, the mode of which has been before described, the operation is continued from one hour to five or six hours, but it is more tedious and less effectual than bucking, where much business is to be done.

After bucking or boiling, the goods were, by the old bleaching process, exposed for at least a week to the air, before they were again submitted to the action of alkaline leys, and this process alternately repeated many times, till the goods were perfectly white, and the goods at last soured and washed off.

To explain the *old method of bleaching* more particularly, we shall add the following process for bleaching linen cloth.

Steep your raw linen cloth in a wood vessel all night, then change the water, and add fresh till you perceive the water to be no longer discoloured by it; rinse, wring, and lay it on the ground, and water it if you have opportunity. When it has thus lain on the grass three or four days, and is dry, take hold of each piece one after the other by the selvedge, and draw the cloth to you, still holding it in the most even manner you can, until you get the further end, with the corners of which further end you tie the cloth very loosely in the middle of the folds, and so lay it in the bucking tub, with the two selvedges upwards.

Thus proceed till you have placed as much cloth in your tub as will cover the bottom of it, taking care not to pack the cloth so close but that your ley may penetrate every part equally. When you have laid the first range of cloth in your tub, pour upon it as much milk-warm ley as will sufficiently soak through all parts of your cloth. Then lay another range in the same manner upon the first, and pour on more ley till that be soaked as the other was, and continue so to do till your bucking tub be full of cloth.

That done, you must begin to buck for twelve hours together, the remainder of your ley having been put in the pan with a slow fire underneath. For the first five hours the ley should not be of a boiling heat; you must from time to time allow some of the ley to run out of the pan upon the cloth in the bucking tub; then increase your fire gradually and slowly, so as in four hours more to bring it to a boil, continuing to put on the ley, and draw it off your cloth in small quantities at a time. When your ley begins to boil, you must let it boil on for three hours, during the whole

time pumping your ley up to the boiler from the reservoir, into which it runs from the cloth, and returning it boiling hot upon the cloth, so that the hot ley may act powerfully and equally upon every part thereof.

After each bucking your cloth must be laid upon the grafs in the bleach-field for some days. The bucking, and exposure on the ground, must be repeated about ten times successively, according to the nature of your cloth; it should then be dried up, soured, and washed well in clean water; if the water is rather warm, the better.

Your two first buckings ought to be from a strong caustic ley of pot-ashes; but afterwards you should abate of that strength, lest it should injure your cloth. Mild ley, or pearl-ash, should be used for the latter buckings, as the cloth becomes nearer white.

This was the management during the summer months; but for four months in winter bleaching was suspended, the operations being periodically interrupted, and the capital of the manufacturers or proprietors of the goods locked up. Even during the bleaching months, their property was long in preparing for sale; as cotton goods, which required from four to six applications or repetitions of alkaline leys, consumed so many weeks in bleaching, whilst linens, which could not be bleached by less than from twelve to twenty applications, could not be brought in a marketable state to the proprietor hardly in six months.

Such was the state of bleaching till Mr. Scheele, a Swede and eminent chemist, discovered the properties of oxygenated muriatic acid, procured by mixing manganese with marine acid, in rendering vegetable matter white; and M. Berthollet, the celebrated French chemist, improved this operation, and actually applied its powers in bleaching cotton goods by interposing its action between the different alkaline operations instead of the tedious exposure of the goods to an uncertain atmosphere; the same effect being produced by immersion of the cloth in this acid, as by laying the goods upon the grafs in the bleach-field, exposed to air and light.

Discovery of and Variations in the Mode of procuring the Oxygenated Muriatic Acid.

By the addition of vitriolic acid to common salt, an elastic aeriform fluid, or muriatic gas, is disengaged, from which with water a marine acid is produced. The mineral substance manganese, or what the modern chemists call oxyd of manganese, contains what was formerly denominated vital air, pure air, or dephlogisticated air, but now named oxygen. Manganese yields oxygen, when marine acid is added to it, and submitted to distillation; the liquor produced by the contact of this oxygen with water, is the oxygenated marine or muriatic acid discovered by Mr. Scheele, about the year 1774, when he observed and applied its effects in rendering colourless vegetable substances of various kinds, more as a matter of curiosity than use.

M. Berthollet, in the year 1786, improved the process of its preparation, applied its power to bleaching or destroying the vegetable colours natural to cloth, the result of which experiments he gave to the world in the year 1789; but, without derogating from the merit of this excellent chemist, it is justice to state, that, previous to any publication by M. Berthollet, Mr. Scheele communicated to M. Kirwan the properties of the dephlogisticated marine acid in whitening vegetable substances, and Mr. Kirwan, then residing in Newman-street, London, suggested to Mr. C. Taylor, the present secretary to the Society of Arts, &c. the probability of its use in bleaching; and a whole piece of callico, in the state received from the loom, was, in the spring of 1788, actually bleached white, printed in permanent co-

lours, and produced in the Manchester market ready for sale, having undergone all these operations in less than 48 hours, by the joint efforts of Mr. Cooper, Mr. Baker, and Mr. Taylor, which is perhaps the first entire piece, either in France or England, that fully ascertained the real merits of the new mode of bleaching, and a certainty that it might be generally useful in commerce. This experiment was immediately followed by the establishment of a large bleaching concern by Mr. Cooper, Mr. Baker, and Mr. Horridge, at Raikes, near Bolton, in Lancashire, and before any considerable bleaching work was actually at work in France.

The ingenious Mr. Watt we believe to be the first person who simplified the process of preparing the oxygenated muriatic acid, by means of a mixture of common salt and manganese, previous to the addition of the vitriolic acid. Soon afterwards the operations of the bleacher were farther facilitated by the substitution of large and commodious stills of lead, instead of glass vessels, and both these improvements have since been in general use.

We shall now proceed to mark the various treatment of the oxygenated muriatic acid when obtained, and the different means which have been adopted to fit it for application in bleaching.

It having been found in the earlier stages of distillation, that common marine acid was produced instead of the dephlogisticated or oxygenated muriatic acid; and from the violence of the ebullition, that manganese itself was sometimes thrown over from the still, M. Berthollet had recourse to an intermediate vessel, containing water, to absorb the marine acid gas, and stop other impurities which might contaminate the oxygenated muriatic gas in its passage through this vessel to the receiver.

It will here be necessary to discriminate the various modes in which the oxygenated muriatic gas has been treated, after passing the intermediate vessel last mentioned.

Mr. Scheele seems generally to have operated with the acid in the state of gas; but M. Berthollet sought to condense it in water, with which he filled his receiver, or wooden vessel, and which water he kept agitated during the distillation, to accelerate the solution or combination of the gas.

The oxygenated muriatic acid, thus prepared, was drawn from the receiver into kiers, or large wooden vessels, where its strength was regulated by the addition of water; after which, the goods to be bleached were immersed therein from six to twelve hours, but most frequently during the night; and though these periods may seem short, they were sufficient to allow the cloth to become more white than could be done by as many days' exposure to the atmosphere and a summer's sun, and were then ready for a fresh application of the alkaline leys.

Such was the bleaching liquor of M. Berthollet; but it was found in practice yet defective, as the volatility of the gas occasioned its speedy separation from the aqueous solution; a decomposition even by light alone in glass vessels took place; a rapid loss in the strength of the liquor when exposed; and much danger to the health of the workmen from its suffocating quality; at the same time, that in extracting the natural colours of the cloth, it also tended to discharge the colours dyed in the yarn, and were along with the gray cotton an imperfection which precluded its use in an infinite variety of British manufactures.

Similar circumstances probably led some bleachers resident at Javelle, in France, to add a solution of caustic alkali to the water in the receiver, and by this means to remedy many of the defects complained of.

But M. Berthollet continued to recommend his process, considering such substance as impairing the bleaching powers;

an idea that was generally maintained by the chemists, but contradicted by the bleachers, whose experience taught them, that though the acid thus combined whitened with somewhat less rapidity, yet it was not eventually in an inferior extent; and the advantages of preserving the colours dyed in the yarn, compelled them to have recourse to the expensive addition of pot-ashes, in preference to M. Berthollet's mode.

Here we shall observe, that, according to the doctrine of the modern chemists, the oxygenated muriatic acid bleaches in consequence of yielding to the colouring matter of the cloth that oxygen which, in the distillation, the acid absorbed from the manganese; or, in the language of Stahl and Becher, that the dephlogisticated marine acid absorbed the colouring matter from the cloth, and was restored to its original state of common marine acid, by regaining that phlogiston which it had, in its preparation, yielded to the manganese.

In the mixture of an alkali with the acid, we have noticed that the bad consequences arising from its volatility have been corrected, and the requisite protection afforded to dyed colours, yet still that its power of whitening cloth was not diminished, nor much more time taken up by the operation; yet, in part from deference to M. Berthollet's opinion, and in part owing to the expense of the alkali, other means to produce the effect were attempted.

One of the first of these, practised by the bleachers of cotton-hose, at Nottingham, was to receive the dephlogisticated muriatic gas into a small air-tight chamber, in the upper part of which the goods were suspended from a frame, whilst at some distance below was water, sometimes impregnated with ley of pot-ash, and sometimes with lime-water, or water mixed with lime. The gas was introduced betwixt the fluid and the goods, amongst which it ascended and mixed; at the same time, by occasionally immersing the goods in the fluid below, it was sought to modify the action of the acid. This was effected by means of a pole, or long lever, connected with the frame on which the goods were suspended, the centre of which pole moved on a swivel fixed in a hole in the partition, occasionally stopped with clay, and enabled a person to let the goods down into the fluid, not always however without inconvenience, which occasioned it the name of the *Bedlam Process*.

Respecting the above process it must be observed, that the acid is much more powerful or active in the state of gas than in any other way; and though the occasional immersion of the goods into the fluid below, corrected in some degree its violent effects, yet the dyed colours disappeared more rapidly in this than in any other process, and the fabric itself was sometimes injured.

The next process attempted by the bleachers, was to put into the receiver, filled with water, a quantity of pulverized lime, then the goods themselves, and the whole agitated during the admission of the gas; the consequence of which was, that the goods thus mixed with lime were partially coated with it; and this coating being unequal, the action of the acid upon it was irregular, leaving at the same time the parts uncoated to receive the whole action of the bleaching powers; hence inequality of bleaching ensued, and an insurmountable difficulty in preserving the dyed colours of the goods to be bleached.

Having noticed the imperfections of the two last processes, we shall observe that lime-water, or a pure chemical solution of lime in water, has been sometimes substituted instead of a solution of alkalies in the receiver, but was not, when used in that manner, found to answer so well as the alkaline solution.

That lime-water could produce no valuable effect beyond what was derived from M. Berthollet's mode, or from simple water, must be evident, when it is considered that water can dissolve no more than $\frac{7}{1000}$ th part of its weight of lime, a quantity wholly insignificant in neutralizing the oxygenated muriatic acid for the purpose of the bleacher; nor could pulverized lime, merely thrown into the water of the receiver, serve a better purpose, since, from its being specifically heavier than the water, all beyond the quantity in chemical solution subsided and remained nearly useless at the bottom of the receiver.

It has been already mentioned, in noticing the application of alkaline leys in bleaching, that the more intelligent bleachers, in preparing their ash-leys, made use of quicklime to augment the power of the alkali, when such alkali was in a mild state, or, in other words, combined with fixed air, or, as it is now termed, carbonic acid; the attraction of caustic lime for the carbonic acid being stronger than that of ashes. Hence, on caustic lime being thrown into mild ash-ley, the carbonic acid, by which the ashes were rendered mild, abandons the alkali to combine with the lime, leaving the ashes in their caustic state.

But, although the attraction of carbonic acid is stronger for lime than for alkali, the contrary is the case with the oxygenated muriatic acid, as it abandons lime to combine with ashes, leaving the lime to precipitate.

This observation is made in order to guard the ignorant bleacher from mistakes, who, from having mixed lime with his ash-ley in the receiver, in the preparation of the oxygenated marine acid, may suppose it acts in a similar manner; but not a particle of lime is acted upon by the acid, whilst ashes remain to combine with it; the only effect of the lime there, being to abstract from the ashes any fixed air they may contain, and so dispose the alkali to absorb more of the oxygenated muriatic acid.

Besides the processes above mentioned, the bleachers attempted to unite the oxygenated muriatic acid with clay; but as the clay has scarcely any affinity with it, the liquor thus made was little, if at all, superior to that of M. Berthollet.

Such were the attempts made from the year 1786; and the oxygenated muriatic acid combined with pot-ash was in general use by the bleacher until 1798, when Mr. Tennant, of Glasgow, by a well-conducted series of experiments, formed what may not improperly be called a new æra in bleaching.

Mr. Tennant, having seen so long a period elapse without any material improvement in bleaching, and the alkali, though an expensive ingredient, regarded by the bleacher as an indispensable article to unite with the oxygenated muriatic acid in the receiver, made some trials with the earths strontites and barytes, and with success. Their solubility in water enabled him to combine them with a sufficient quantity of oxygenated muriatic acid to serve the purpose; but the scarcity of strontites, and the difficulty of separating barytes from the vitriolic acid, with which it is usually found in combination, rendered these discoveries rather objects of curiosity than use.

Mr. Tennant had previously made experiments to combine the oxygenated muriatic acid with lime and lime-water, in the modes above-mentioned, but found they were not adequate to the purposes intended; the lime in general remaining at the bottom of the receiver uncombined with the gas, which was the necessary consequence of the lime being specifically heavier than the water, and the gas much lighter; the water, by its interposition betwixt the two substances which ought to be combined, namely the oxygenated muriatic gas and the lime, preventing their union. To bring the pulverized lime into contact with the gas as quickly as

it entered the receiver, became then the object of his attention; and for this purpose he found it was necessary to keep the lime floating, or diffused through the fluid, which he succeeded in accomplishing by two different methods; one of which was by increasing the specific gravity of the water in the receiver, by the addition of common salt, and thus retarding the lime from subsiding; the other mode was by constant agitation of the lime in the water in the receiver, to keep the lime diffused through the fluid, during the time the oxygenated muriatic gas was introduced; and by this means he succeeded in uniting and retaining a much greater quantity of gas with the mixture, than by any method heretofore used, and without the addition of any ashes or alkaline substances.

A very material advantage was gained by this discovery; namely, that it uniformly afforded security to the dyed colours in a superior degree to the alkaline ley.

It is well known, that in the alkali of commerce, such as pot-ash or pearl-ash, a large and very irregular proportion of neutral salts is intermixed, which are soluble along with the alkali in water, thereby so far contaminating the ley, that the bleacher is always uncertain what quantity of pure and active alkali it contains. In bucking or boiling cotton goods, the detriment from these neutral salts is not so great, as a repetition of the process may compensate for those admixtures in the ley: but in the bleaching liquor formed by the mixture of the oxygenated muriatic gas with such ley, if there is a deficiency of alkali, the uncombined oxymuriatic acid immediately attacks the dyed colours of the goods, and discharges them, and thus considerable damage frequently occurs before the real origin of the evil is ascertained and corrected. The bleacher is kept in a constant state of alarm respecting the quality of the ashes he makes use of, besides the great cost of their purchase. In using lime for the same purpose, the expence is a mere trifle; what is not combined with the oxymuriatic acid precipitates, after the agitation is over, leaving a pure liquor free from all uncombined acid.

Simple as the combination of the lime with the oxygenated muriatic acid may now appear, yet it was a long time attempted in vain; but this, perhaps, will not be such a matter of surprize, when we reflect that the French chemists, whose opinions were regarded generally as law by the common bleachers, and whose treatises on the subject of bleaching were almost the only accounts published, considered lime as no farther useful in bleaching, than in absorbing the carbonic acid or fixed air usually combined with alkalies or ashes; and thus rendering the alkaline ley more disposed to unite with the oxygenated muriatic gas, when exposed to its contact in the receiver, to form, as it is called, the liquor de Javelle; or when intended for use as a mere alkaline ley, to render its action more powerful on the oily particles in the vegetable fibre, on a similar principle to the formation of soap.

An excellent treatise on the subject of bleaching, in the English language, viz. "The Report on Experiments made by order of the right honourable the trustees of the linen and hempen manufactures to ascertain the comparative merits of specimens of oxygenated muriatic bleaching liquids," published at Dublin in the year 1791, in claim of a bounty offered by the trustees, appears to convey no further knowledge of the use of lime in bleaching at that time than in promoting the separation of the carbonic acid from the leys, whether they were afterwards to be used alone, or in the preparation of the oxygenated muriatic acid. Mr. Rose's experiments in this report contain, however, much useful information, which we shall further notice.

The simplicity of Mr. Tennant's invention of retaining a greater quantity of the oxygenated muriatic gas, by agitation of a sufficiency of lime in the water of the receiver, should be no derogation to its real merit. In substituting lime for pot-ash, an article, not only of foreign produce, but expensive, he has benefited this country, to an extent almost beyond conception; it having been proved upon oath, that by the use of Mr. Tennant's process, the consumption of ashes at a single bleaching-green has been reduced three thousand pounds sterling in value in one year. A patent for Mr. Tennant's invention was granted him in the year 1798; but as frequently happens in patent causes, on a late trial of its validity, some circumstances arose from which the jury thought themselves justified in reverting the patent; we have therefore with considerable pains collected for the public benefit an account of his process, and the most approved mode of putting it in practice, either on a small or an extensive scale, as will be seen by a reference to *Plate I. of Bleaching* hereafter described.

Mr. Tennant's method of using calcareous earth for neutralizing the muriatic acid gas, and forming the oxy-muriat of lime employed in bleaching is as follows; viz.—In a receiver capable of containing one hundred and forty gallons wine measure, dissolve thirty pounds of common salt, which appear useful only in giving an additional degree of specific gravity to the water, and by that means making it easier to keep the lime to be afterwards added, in suspension; when this salt is dissolved, add sixty pounds of finely powdered quicklime, and into the retort of the apparatus put thirty pounds of powdered manganese, mixed up with thirty pounds of common salt, upon which pour thirty pounds of sulphuric acid (oil of vitriol), previously diluted with its bulk of water, and the usual precaution of luting the vessel being taken, proceed to distillation. When the gas begins to appear, the agitation of the lime and water in the receiver must commence, which should be continued by means of a wooden paddle or rake, or similar contrivance, without intermission, until the materials in the retort, after heat being employed as usual, will not yield any more oxygenated muriatic acid gas. Then the whole should be allowed to remain at rest for two or three hours; when the clear liquor in the receiver, may be drawn off for use, and mixed with water in such proportions as may be found necessary, previous to the immersion of the goods to be bleached.

The principal point of attention in preparing this oxygenated muriat of lime is, to obtain a complete diffusion of the lime through the mixture, or a mechanical suspension of it in the water during the operation, so that every particle of the lime may, by agitation, be exposed to the action of the gas, instead of merely its upper surface, as had been formerly practised. By the present means, the oxygenated muriatic acid gas is absorbed with ease, and meets with a sufficient quantity of lime to produce a strong solution of oxygenated muriat of lime, without any uncombined oxygenated muriatic acid; a thing which could not be otherwise effected. The addition of the common salt in the receiver may even be omitted, without prejudice, if the agitation of the lime be well managed.

Plate I. fig. 2. of Bleaching, shews a longitudinal section of a method, which has been practised in Ireland for distillation of the oxygenated muriatic acid, and the formation of the oxygenated muriat of lime. *a*, the ash-hole; *b*, the fire under the iron pot or vessel; *c*, the aperture through which it is supplied with coals; *d*, the entrance to the ash-hole, which may be provided with a stopper of burnt clay, or earthen ware, to regulate the draught of the fire, by means of the handle shewn by dotted lines: *e*, a cast-iron pot or

vessel, nearly filled with water, in which the leaden retort is placed; *f*, a tripod of iron, on which the retort stands; *gg*, the leaden retort, from which the gas is to be distilled; *b*, a tunnel of bent lead, through which the oil of vitriol (sulphuric acid) is to be introduced into the retort; *i*, a leaden cover, fitted and luted to the neck of the retort, having three apertures, viz. for the introduction of the tunnel, the rod of the agitator, and the tube of the condenser; *k*, the agitator, formed of a rod of iron coated with lead, having some arms at its lower end to stir the materials within the retort. At the part where the rod passes through the cover, a leaden collar or cap is foldered, to prevent the agitator from descending too low; these two parts are made in a conical form, to fit exactly, and thus prevent the escape of the gas; *l*, a leaden tube or pipe, of three inches bore, to conduct the gas into the tubulated reservoir; *m*, the leaden reservoir, formed upon the principle of Wolfe's apparatus; the tube, *l*, descends by the first aperture, *m*, to the bottom of the reservoir, which is about two thirds full of water. The small portion of sulphuric acid, which rises in distillation, unites with this water; the oxygenated muriatic acid, which traverses this water, passes by the pipe, *n*, into the receiver or condenser, *oo*, which is a wooden vessel, in the midst of which is placed an agitator, *p*, the arms of which raking up the lime cause it to combine with the gas, in proportion as it arises in bubbles from the lower extremity of the leaden pipe, *n*.

The projections of wood, *qqqq*, fixed to the staves within the tub, counteract the rotatory motion of the arms of the agitator, and thus assist the combination of the gas with the lime and water. The cover of this tub is fixed close upon the edge of it at *r*; the cover having a groove in it to unite them tighter together; *s*, a cock to draw off the liquor, when sufficiently impregnated for use; *t*, a wooden handle to give motion to the agitator. The joints may be luted with clay, to prevent the escape of the gas.

Fig. 3, and 4, shew Mr. Tennant's improved machinery for preparing the oxy-muriat of lime. The outline, A, (fig. 3.) is the still, made of lead, of a circular form, having a double flange at the top, which is filled with water, to prevent the gas from escaping in that direction. B, the leaden cover of the still, having a flange on the under side, which goes into the double flange of the still, and having a double flange on the upper side, which is filled with water; the inner part of this double flange consists of a short tube, which goes quite through the cover, opening by this means a communication with the still, and allowing the gas to escape through the long leaden pipe inserted into it, and from thence into the receiver, as explained at fig. 4, where there is a section of the still, furnace, and receiver; *a*, the still; *b*, an iron pan in which the still is placed on an iron stand; this pan is then nearly filled with water; *c*, the fire-place; *d*, the furnace door; *e*, the air-hole; *f*, double flange filled with water; *g*, the cover, with flanges on the upper side filled with water. D, the receiver, made of wood, and lined with lead; *i*, a double flange filled with water, the interior pipe communicating with the inside of the receiver, and bent horizontally as at *l*, from whence the gas issues into the receiver; *h*, *h*, two short pipes inserted in the top of the receiver, through which the rods of the agitators have a free motion; *m*, *m*, a stopper in the top of the receiver, closed when the receiver is at work, but sufficiently large, if removed, to admit a person into the inside to repair or cleanse it, when necessary; *n*, *n*, two paddles, or agitators, generally of a square form, and of a similar construction to the head of a churn staff; *o*, *o*, the rods of the agitators attached by iron pins to the lever, *q*, which lever has sits at

the place of junction, to allow the rods to rise and fall perpendicularly; *p*, the fulcrum or support of the lever; *q*, the lever, which, by a proper motion communicated to it, alternately raises and depresses the agitators in the receiver; *r*, a rod connecting the lever *q*, with the lever *s*, which last lever is put in motion by the wheel E; *t*, a balance weight placed at the other end of the lever; the beam supporting the fulcrum of the lever being near the letter *s*. E, the wheel to be put in motion by water, or in any other way, having a crank, *u*, communicating by an upright shaft with the lever *s*.

It will be found that the flanges, filled with water, preclude the necessity of the application of any lute, and occasion the operation to be conducted in a cleaner, cheaper, and more expeditious mode, than formerly employed.

To describe the proportions of the several articles used in the process of bleaching, would carry us far beyond the bounds which can be allotted in the present publication; we shall, therefore, give the following short but clear account of the mode we recommend to be practised, to procure the most perfect and durable white on cotton goods, after their being taken from the weaver; which is, first, to wet them thoroughly in cold water; then to allow them to steep in cold, or lukewarm water, from 12 to 36 hours, according as they are of a strong or thin fabric; then to wash them well in clean cold water; afterwards to buck or boil them in a caustic alkaline ley; then to wash the goods well in clean water, and afterwards immerse them in diluted oxymuriate of lime, and wash them, repeating the operations of the alkaline leys, and the oxymuriate of lime, till the goods are perfectly white; then to pass the goods through the diluted sulphuric acid liquor, washing them well afterwards; lastly, to pass them through a weak ley of pearl-ashes, or of soap, and again through clean water, before drying and finishing them; which finishing of the goods consists in starching, blueing, rolling, or callendering them as fashion directs, or the particular market for which they are intended, may require.

It is to be remarked, that the immersion of the goods in the vitriolic sours, and also in pearl-ash, or soap liquor, is necessary at the end of the process, to prevent a brown hue which the cloths that are bleached white from the oxygenated muriatic acid, without such precaution, are apt to revert to.

By experiments made at Rouen on cotton thread, with a view to ascertain whether the old or new mode of bleaching was more prejudicial to the fabric, it was proved that the cotton thread bleached in the new mode bore, without breaking, considerably more weight than that bleached in the old method, and was less injured in texture.

In the report on experiments, made by order of the trustees of the linen and hempen manufactures at Dublin, in the year 1791, with a view to ascertain the comparative merits of several specimens of bleaching liquids sent for their examination, the following mode of bleaching appeared to be the best for linens, and though executed on a small scale, will convey the principal necessary information.

May 11th, 1791. The linen was steeped, in the flask received from the loom, into water of a heat sufficient to bear the hand, and left in the vessel.

May 16th. The linen was washed out of the liquor, in which a pretty strong fermentation was observed to be taken place.

May 17th. Boiled making a mother-ley, which was made in the following manner: three pounds and a half of lime were slaked, and mixed with ten gallons of water; fourteen pounds of Dutch pearl-ash were dissolved in some of this water; then mixed the whole; when it had settled, a

was filtered through a coarse cloth, and the residuum washed repeatedly in four gallons of water, to obtain the whole strength of the alkali; the whole fourteen gallons being then carefully mixed, the ley proved, by very accurate weighing, to contain twelve ounces of caustic alkaline salt to the gallon. From this, a ley was made from the work, by adding six parts of water to one of the mother ley; thus each gallon of the working ley contained one ounce, five drachms, and forty-three grains of caustic alkali.

The boiler being charged with this ley, the linen, which had been spittle washed, was steeped in it cold for one hour; then brought up by a very gentle heat to a simmering boil, which was continued for three hours; the cloth was then well washed out, and left in steep for that night.

May 18th. Washed out the above linen in fresh water; hung it on cards in the open air, watering it several times in the day.

May 19th. Finding the cloth not so well cleared as could be wished, the boiler was again charged with one of mother-ley, to four of water, which made the strength two ounces, three drachms, twelve grains of caustic alkali to the gallon. In this was boiled another piece of linen which had been spittle washed as the others; and after it was boiled, it was well washed out.

May 20th. Steeped the whole of the linens for six hours in the liquid prepared with the oxymuriatic acid of the several claimants; afterwards washed them well out, and left them steeping in cold water all night.

May 21st. Washed out all the above linens, and when dry, boiled the whole parcel as before in one of the mother-leys, to five of water, containing two ounces of caustic alkaline salt to the gallon; washed them well out of the ley, and left them to steep in pure water till Monday morning, the 23d instant.

May 24th. Steeped the linens for the second time in the oxygenated muriatic acid for six hours; then washed them out, and left them to steep all night in cold water.

May 25th. Having charged the copper with a ley made from one of mother-ley, to six of water, containing one ounce, five drachms, and forty-three grains of caustic alkaline salt to the gallon, the linens were boiled in this for the third time, with a very gentle simmering heat for three hours; they were then washed out, and left to steep.

May 27th. Steeped all the linens for the third time six hours in oxygenated muriatic acid as before; washed them out, and left them in water all night.

May 28th. Immersed all the linens which had been steeped yesterday in the oxygenated muriatic acid, in a weak vitriolic acid for four hours; then washed them out, and left them steeping in cold water.

May 29th. Washed and dried the linen cloth which had been soured yesterday.

June 1st. Boiled all the linen which had been soured in a strong lather of soap.

June 2d. Soured and washed out all the linen which had been boiled in a soap lather yesterday. This operation finished that experiment, in which the above linens were first steeped in water; then boiled in caustic alkaline ley, and steeped in oxygenated muriatic acid alternately four times; then soured in vitriolic acid, soaped and soured again.

The above experiments were made, with various others, by Mr. John Arbuthnot, and Mr. John Clarke; and on the trials of the different specimens of the oxygenated muriatic acid, the preference was given to that prepared by Mr. Robert Roe, of Bing's End, on the principle of the javelle liquor mentioned by Mr. Bartholles, by adding a solution of alkali in water in the receiver. Mr. Roe's best prepara-

tion, of which was made by adding thirty-eight pounds of quicklime to 114lb. of pearl-ash, which made a caustic ley of about nine pounds weight per gallon; he found caustic ley more susceptible of imbibing the gas and retaining it, than mild ley of equal strength.

From the different experiments made to bleach various articles at the above time, the following inferences may be deduced, viz. that allowing cotton or linen, when raw from the loom, to ferment, by steeping in warm water a considerable time before boiling the cloth in an alkaline ley, is of considerable service.

That cloth or yarn is not injured by steeping for six hours together in oxygenated muriatic acid.

That strong alkaline leys answer better than weak ones, at the commencement of using the leys.

That the white colour of bleached cloth can be better judged of wet than when dry.

That very minute attention in excluding light and air is not absolutely necessary in bleaching with oxygenated muriatic acid.

That purging or clearing yarn or cloth in an alkaline ley, previous to steeping in oxygenated muriatic acid, is absolutely necessary.

That the bleaching liquids made from oxygenated muriatic acid, in which alkaline salt is blended in the composition, require the cloth to be frequently steeped in vitriolic acid; and that the oxygenated muriatic acid made with water only, make more frequent boilings of the cloth in alkaline leys necessary.

That the loss of the cloth in weight, when bleached by the new method, is only one fourth, but by the old method one third.

That steeping in warm water is infinitely better to extract the fowen and dirt from the raw cloths, than boiling them with soap or ley immediately as they come from the loom.

The liquors of the oxygenated muriatic acid, and also those made from the vitriolic acid, may be repeatedly used without detriment, till the whole strength is exhausted.

The cloth or linen, in the acid bleaching liquors, should be moved in the liquor every hour, that every part may be equally cleared.

It is difficult to ascertain the strength of the leys proper for use in bleaching cotton or linen, as the alkalies or ashes differ so greatly in purity, and the admixture generally found in them of neutral salts prevents the hydrometer from being a regular test. The common allowance for bleaching linens in Ireland, is stated by Mr. Higgins, in his ingenious memoir in the Transactions of the Dublin Society, to be for sixty gallons of water, six pounds of barilla, or four pounds of pot-ash at the least, and most bleachers use more than this.

To discover adulterated pot-ash, Mr. Higgins recommends the following method. The specimen of ashes being first weighed, is digested for a few minutes on a sand-bath, in twice its weight of water, in a heat of about 212 degrees, and instantly stirred. It is then removed from the sand-bath, and before it is cooled to the temperature of the atmosphere, it must be filtered through paper. When all the liquor has passed through the filter, a small quantity of cold water is gradually poured upon the saline residuum or the filter, in order to wash through the whole of the alkali. The undissolved salt sulphate of pot-ash (vitriolated tartar,) remaining on the filter, is afterwards dried and weighed, to ascertain the quantity.

To determine whether any common salt is suspended in the liquor which has been filtered, evaporate the clear solution a little on a sand-bath, and set it in a cold place for 24

hours; at the end of which time, any common salt it contains will be found crystallized in regular cubes at the bottom of the vessel; pour off the clear liquor, and repeat the process, till no more cubic crystals are produced. If it is desired to be very accurate in the analysis, before the common salt (muriate of soda) thus procured is weighed, some muriatic acid may be poured upon it, in order to take up any of the pure pot-ash which may have adhered during its crystallization. The muriatic acid, with such of the alkali as it has dissolved, may be then drained off and thrown away, and the muriate of soda dried and weighed.

The sum of the impurities being then subtracted from the weight of the specimen, the quantity of the pure pot-ash is ascertained.

To shew what quantity of mere alkali is contained in 100lb. avoirdupois of several different alkaline salts examined by Mr. Kirwan, we shall add the following table, published by him in the Irish Transactions, in 1789.

One hundred Pounds.		Mineral Alkali.	
Crystallized soda	- yielded -	20lbs.	
Sweet Barilla	- - -	24	
Mealy's cuneamara kelp	- - -	3.437	
Do. desulphurated by fixed air	- - -	4.457	
Strangford kelp	- - -	1.25	
One hundred Pounds.		Vegetable Alkali.	
Dantzic pearl ash	- yielded -	65.33lbs.	
Clarke's refined ash	- - -	26.875	
Cashup	- - -	19.376	
Common raw Irish weed-ash	- - -	1.606	
Do. slightly calcined	- - -	4.666	

It is much to be regretted that, considering the immense quantities of pure marine alkali which could be procured at a cheap rate from the East Indies, that so little attention should be paid by the East India company to an article which would be so profitable a branch of commerce to them, and prevent a considerable sum being paid to other nations. The mineral alkali procured from the East Indies, is much purer than what is obtained from Barilla; and a preparation exactly similar in appearance and quality to the Alicante Barilla, may be made with great advantage to the manufacturer, from a mixture of the East India mineral alkali with the common Scotch kelp, for the purposes of the bleacher, the soap maker, or the Turkey-red dyer. To shew the importance of this object, the following table of the imports into Great Britain are annexed for seven years.

	Barilla.	Pot-Ashes.	Pearl-Ashes.
1796	86.723 cwt.	62.829 cwt.	45.290 cwt.
1797	51.105	57.826	36.074
1798	123.990	81.482	60.691
1799	146.163	77.246	51.792
1800	175.629	135.400	45.161
1801	63.210	90.523	54.835
1802	151.796	48.054	64.288

When it is considered that 20 pounds of the mineral alkali brought from India in a powdery state, as it usually is, will, by mere solution in water, yield 100lbs. of the crystallized soda (sold in the shops, it will be seen, that the purchase of the mineral alkali from the East India company, will be an object well deserving the attention of the bleachers and soap-boilers; and far preferable to the use of Spanish kelp or Barilla.

Mr. Kirwan, by means of muriatic acid, precipitated the colouring matter from an alkaline ley, saturated with the colouring matter of linen yarn, and found it to possess the following properties. When suffered to dry for some time on a filter, it assumed a dark green colour, and felt somewhat

clammy, like moist clay. His observations in the Irish Transactions for 1789, are as follow:

"I took, says he, a small portion of it, and added to it 60 times its weight of boiling water, but not a particle of it was dissolved. The remainder I dried in a sand-heat; it then assumed a shining black colour; became more brittle, but internally remained of a greenish yellow, and weighed one ounce and a half."

"By treating eight quarts more of the saturated ley in the same manner, I obtained a further quantity of the greenish deposit, on which I made the following experiments:

1st. Having digested a portion of it in rectified spirits of wine, it communicated to it a reddish hue, and was, in a great measure, dissolved; but by the addition of distilled water, the solution became milky, and a white deposit was gradually formed; the black matter dissolved in the same manner.

2d. Neither the green nor the black matter was soluble in oil of turpentine or linseed oil, by a long continued digestion.

3d. The black matter being placed on a red hot iron, burned with a yellow flame and black smoke, leaving a coaly residuum.

4th. The green matter being put into the vitriolic, marine and nitrous acids, communicated a brownish tinge to the two former, and a greenish to the latter, but did not seem at all diminished.

"Hence, it appears, that the matter extracted by alkalis from linen yarn, is a peculiar sort of resin, different from pure resins only by its insolubility in essential oils, and in this respect resembling lac. I now proceeded to examine the powers of the different alkalis on this substance, eight grains of it being digested in a solution of crystallized mineral alkali, saturated in the temperature of 60°, instantly communicated to the solution a dark brown colour; two measures (each of which would contain eleven pennyweights of water), did not entirely dissolve this substance. Two measures of the mild vegetable alkali dissolved the whole."

"One measure of caustic mineral alkali, whose specific gravity was 1.055, dissolved nearly the whole, leaving only a white residuum."

"One measure of caustic vegetable alkali, whose specific gravity was 1.039, dissolved the whole."

"One measure of liver of sulphur, whose specific gravity was 1.170, dissolved the whole."

"One measure of caustic volatile alkali dissolved also a portion of this matter."

The colouring matter of cotton is much more soluble in alkali, than that of linen: hence the greater facility with which cotton is bleached.

The theory of bleaching vegetable matter, as we have before observed to have been described by Mr. Delaval, depends on removing the colouring matters, whether natural or accidental, which cover their solid fibrous parts, which are the only parts endued with a reflective power.

Raw cotton or linen, boiled in a diluted solution of caustic alkali, gives to the liquor a deep brown colour, and destroys its causticity; and fresh portions of clear ley applied a second or third time, will produce a similar effect, but in an inferior degree. If the cotton or linen be now plunged into the oxymuriatic acid, and allowed to remain a short time, they will become white; and if they are then plunged into an alkaline ley, the liquor will again become brown, and lose its causticity.

On saturating either the first or last of the alkaline solutions with an acid, a similar precipitate is obtained from each, of a dark coloured matter, almost insoluble in water, but soluble in caustic alkali.

Hence it appears, that after raw cotton or linen has been acted upon by alkalies for two or three times, they have no further effect upon it, till the cloth comes in contact with oxygen or pure air, either by immersion in the oxygenated muriatic acid, or by exposure to the atmosphere; and it is on account of the speedy action of the acid, in comparison with that of the atmosphere, that the new mode of bleaching is now generally adopted.

M. Berthollet, and the modern chemists suppose, that the colouring matter of linen is composed principally of carbon and hydrogen; and they conclude, that linen, bleached by the oxymuriatic acid, becomes yellow on this principle, that when the oxymuriatic acid renders linen white, a quantity of oxygen has combined with the colouring particles; but that this oxygen gradually enters into a combination with the hydrogen, and forms water which passes off; that then the carbon becomes predominant, and the linen, in consequence, assumes a yellow colour.

The old chemists, on the principles of Stahl, would say, that a part of the dephlogisticated marine acid, (oxymuriatic acid,) after the cloth had been acted upon by the alkali, absorbed such phlogistic colouring matter from the cloth, as the alkali had no affinity for; and thus became diluted common marine acid, which has a great attraction to cotton or linen, and, if exposed to a moderate heat, will act upon the texture of the cloth, and render it of a yellow colour.

We notice this circumstance in two different points of view, that the bleacher may be aware of the necessity of applying, in either case, a weak ley of pearl-ash, ultimately after the use of the muriatic acid, to prevent this yellowness from occurring; and also that the reader may comprehend the reasoning of Hume, and other persons who have written upon the subject of bleaching, previously to Mr. Scheele's discovery.

To recover the pure alkali from the black coloured leys, which have been used in bleaching, and to render them equally proper for the same purpose, has been for a considerable time a material object in the neighbourhood of Manchester, and practised with great success.

To effect this, the black or brown strong leys, which have been left after bucking linen, or cotton yarn, or goods, or saved after wringing them, is put into an oblong flat shallow iron pan, made of plate iron, rivetted together. (See *Plate IV. fig. 4, 5.*) Under this pan a fire is made, and the old leys gradually evaporated, till they become of a consistence nearly resembling tar; the matter is then put into casks, and carried to the reverberatory furnace, *Plate IV. fig. 6, 7.* where it is laded or poured into the cavity or bed within the furnace; the fire being then made, acts powerfully on the alkaline mass; gradually dries the water left amongst it; then acts on the colouring matter the ley has abstracted from the cloth, which is partly dissipated in a black, offensive smoke, and partly destroyed by combustion; the calcination of the ashes is assisted from time to time, by raking them up with a long iron rod, in order to expose fresh surfaces to the flame; the heat is continued and increased till the inflammable matter amongst the alkali is dissipated, and the ashes brought to a perfect fluid state; they are then let out by an aperture in the side of the furnace, into an old iron pot put into the ground, and when cold, broken into small pieces for use, being frequently in a purer state than when first imported.

Fig. 4. Plate IV. is a section of the evaporating pan for the waste leys, where A represents a flat iron pan, of an oblong square form, about six inches deep, and of a size proportionate to the quantity of leys to be evaporated; B, the fire-place; C, the ash-hole; D, the flue in which the fire

acts under the pan; E, the chimney for the smoke; F, the brick work.

Fig. 5. Plate IV. is a bird's eye view of the same evaporating pan, which is made of plates of beaten iron rivetted together, as shewn in the plan; the fire-place underneath it is marked by dotted lines at B, and the chimney flue at E.

Fig. 6. Plate IV. represents a longitudinal section of the reverberatory furnace used in the preparation of ashes, or solid alkaline salts from the old leys after evaporation, to a proper consistence; a the brick work; b, the ash-hole; c, a channel, or passage under the furnace, to admit a free current of air; d, the fire-grate; e, the fire-place; f, the inner part of the furnace; g, the bed of fire proof brick, on which the matter is calcined; h, the alkaline ley to be calcined; i, a door through which the ley is introduced by an iron ladle into the furnace, and through which door the matter, during calcination, is stirred from time to time; k, the passage for the smoke, or chimney, which chimney should be from 20 to 30 feet high; l, the upper part of the furnace, arched like an oven; m, the separation wall between the fire and matter to be fluxed or calcined.

Fig. 7. Plate IV. represents the upper plan of the furnace, of which *fig. 6.* is a section; a, the outer walls; b, the ash-hole and draught-hole; c, the iron grate of the fire-place; g, the basin in which the leys are calcined; m, the door through which fossil coal is thrown into the fire-place; n, an iron tube through which the ashes in fusion flow out of the furnace when sufficiently calcined; o, an iron pot into which the melted ashes flow, and where they are suffered to cool; p, a wall of fire-brick between the fire-place and basin, over which wall the fire passes; r, the steps leading down to the ash-hole.

It is necessary to remark, that all the interior part of the reverberatory furnace should be made of Welsh brick, or such as will withstand the action of a strong fire; the whole building should be well bound together by iron bars, or cramps. If so constructed, it will last for several years; and when it then wants repair, the ashes, which will be found accumulated in the interstices of the brick-work, will defray the expence of such repairs.

Having shewn the methods generally used in bleaching linen and cotton, we shall notice a process lately discovered by Mr. W. Higgins of Dublin, for using the sulphuret of lime, as a substitute for pot-ash in bleaching. The sulphuret is prepared in the manner following, viz. sulphur or brimstone in fine powder, four pounds; lime well slaked and sifted, twenty pounds; water sixteen gallons; these are all to be well mixed, and boiled for about half an hour in an iron vessel, stirring them briskly from time to time. Soon after the agitation of boiling is over, the solution of sulphuret of lime clears, and may be drawn off free from the precipitate, which is considerable, and which rests upon the bottom of the boiler. The liquor, in this state, is nearly of the colour of small beer, but not quite so transparent.

Sixteen gallons of water are afterwards to be poured upon the remaining precipitate in the boiler, in order to separate the whole of the sulphuret from it; the matter is then well agitated, and must, when settled, be drawn off, and mixed with the first liquor; to these again thirty-three gallons more of water may be added, which reduce the liquor to a proper standard for steeping the cloth.

Though either lime or sulphur, separately, is very little soluble in water, yet this sulphuret of lime is highly soluble.

This preparation has been applied, in the following manner, to the bleaching of linen in Ireland.

The linen, as it comes from the loom, is charged with the weaver's paste or dressing, to discharge which, the linen must be steeped in water for about 48 hours, and afterwards taken out and well washed; in order to separate the resinous matter inherent in the vegetable fibre, the linen must then be steeped in the cold solution of sulphuret of lime (prepared as above), for about 12 or 18 hours; then taken out and well washed; when dry, it is to be steeped in the oxymuriate of lime, prepared by Mr. Tennant's process, for 12 or 14 hours, and then washed and dried. This process is to be repeated by six alternate immersions in each liquor, which are sufficient to whiten the linen.

Though we must confess, that we have some doubts respecting the application of sulphuret of lime to supersede the use of ashes, in bleaching goods intended to remain perfectly white, yet we think it incumbent upon us to state, that for goods previously bleached for dying, it possesses advantages over those where alkalies have been used, and which has been actually proved above 30 years ago, by the practice of Mr. Peter Henry Otterfen, communicated by him to the late Mr. John Wilson, of Ainsworth, near Manchester. Mr. Wilson's memory deserves every mark of respect from the cotton manufacturers of England, for his numerous improvements in the bleaching, dying, and finishing of cotton goods.

For the use of private families, where the linen is dirtied by perspiration or grease, it will be of great service towards rendering it white, to steep it for some time in a clear liquor, made by mixing one quart of quicklime in ten gallons of water, letting the mixture stand 24 hours, and then using the clear water drawn from the lime. After the linen has been steeped in this liquor, it should be washed as usual, but will require much less soap to be used.

Cotton goods, after bleaching, were formerly dried in the open air, on frames or tenter rails, or on rails in covered buildings, or in large rooms or stoves heated for the purpose, all which modes were attended with great delay and disadvantages.

These difficulties were removed in 1797 by an apparatus, simple in its construction, easily managed, and of singular use in facilitating the process of the bleacher. For this useful invention the public are indebted to John Burns, esq. of Paisley.

By this discovery the bleacher can erect a drying machine, equally useful at all seasons, and in all weathers, at less than one-tenth of the expence of former constructions, for doing business to the same extent. There is no risk of damage from wind or rain, less chance of injury from servants, owing to the simple manner in which the goods are prepared. They receive a fine gloss during the process of drying, the colour is as well preserved as if dried in the open air, and they cannot be injured by the heat.

A contrivance so obviously beneficial and complete, was soon introduced into general practice in the west of Scotland; and so undoubted were the claims of the above gentleman to the originality of invention, that the bleachers in the neighbourhood presented him with a handsome donation of silver plate, suitably inscribed, in testimony of their sense of his merit, and as some reward for communicating his plan to the public.

We are more particular in noticing this circumstance, as some other persons have subsequently taken out a patent for the same principle, with a little variation in the construction of the machine, but which alteration has not been found to answer the purpose as expected. We shall therefore now more particularly describe Mr. Burns's apparatus for drying.

Fig. 1. Plate III. A is the boiler or steam vessel; B, the

safety valve; C, the hollow leaden pipe which conveys the steam from the boiler to the rollers; D, a brass cock hollowed to receive the pivot of the roller, represented in *fig. 2*. one of which cocks is fixed to the pipe under each roller, and by opening which the steam is admitted into the roller; E represents twelve rollers placed upon the cocks, one of which, next to D, has the cloth upon it in the operation of drying; FFF, the wood frame in which the machinery is placed; GGG, the supporters of the leaden steam pipe, and of the trough HH, which trough is 15 inches broad at top, to receive the water formed by the condensed steam as it drops from the bottom of the rollers, E, and to conduct it to I, a small pipe extending from the trough, H, to the funnel, K, which funnel has its lower pipe reaching to within eight inches of the bottom of the boiler, to prevent the steam from issuing out at its mouth, and which funnel keeps the boiler supplied with water to its proper height, or shews when any is wanted, as the steam would arise through it if water should be wanting in the boiler.

*Fig. 2. Plate III. shews one of the rollers separate from the frame. It is usually five feet long, one foot in diameter, and made of double tinned sheet iron, and hollow in the middle, for containing the steam; a is the lower pivot of the roller, which is an open tube at the end for receiving the steam conveyed through it from the cock. This pivot rises a foot within the roller, at the under part of the roller; at d is a small hole for allowing the condensed steam to drop into the trough placed below it as above-mentioned; b, the other pivot or axis of the roller, which is fastened to the top bar of the frame by a latch, as represented in *fig. 1*; c, a row of teeth fixed into a small slip of tinned sheet iron, folded to the roller, and thereby elevated to prevent the teeth from tearing the cloth.*

Fig. 3. Plate III. a machine about three feet in height, for the purpose of lapping the cloth upon the rollers. A, the box in which the cloth is first laid; B, the farthest wooden roller, over which the cloth passes from A, and from thence under the wooden roller C, to the tin roller D, on which it is lapped by turning it with the handle E; F, the cloth passing under the roller C, to the tin roller D, on which, when it is lapped, it is ready to be carried and placed in the drying machine; G, a weight hung from the projection in the frame at H, over the roller B, to keep the cloth sufficiently tight as it passes from the box A, over that roller to be lapped on the drying roller D.

Fig. 4. Plate III. shews another method of lapping the cloth on the tin roller, previous to its being dried. A, a perpendicular frame in the front of which is placed the tin roller B, with a handle for turning it at C; the cloth D extends from the roller B over the wooden roller E, in a frame F to G, where its other end is attached by a wire run across it to some wrapper or linen cloth, fastened to a board H, fixed below the roller B. LL are upright posts fixed to the outer side of the bottom frame KK, having wooden pegs NN in them, on the side nearest the tin roller B. Rails or rods are laid across from these to similar pegs opposite, to prevent the cloth touching the ground when it is adjusting in the beginning of the operation, and the number of these posts necessary, therefore, are in proportion to the length of the cloth.

At the commencement of lapping the cloth on the tin roller B, the frame F, moveable on small rollers II, running in grooves on the frame KK, is drawn so far back, that when the cloth is fastened to the wrapper G, one half of the piece reaches to the roller F, the other half passed over that roller, reaches to the tin roller B, to which it is then to be fastened. On turning the handle C, the cloth is gradually lapped round

the roller B, the moveable frame F being drawn forward by the cloth; for as the cloth is lapped on the roller B, the frame F is drawn towards it betwixt the uprights L I, and by means of a projecting wood forming an inclined plane fixed at M, on each side, near the top of the frame F, the rails O are raised off the pegs NN, and carried forward on the part M of the frame F, without impeding its progress to the tin roller B, till the wrapper G, to which the cloth is fastened; passes over the roller, and the wire at G, which attaches it to the cloth, is withdrawn, leaving the whole of the cloth to be dried on the tin roller B, which roller is then taken out, and placed in the drying frame.

To ascertain the strength of the oxygenated muriatic acid used by the bleachers in France, Mons. Deferoizilles made use of a solution of indigo in the vitriolic acid, for which purpose he takes one part of finely pulverized Guatimala indigo, and eight parts of concentrated vitriolic acid, which mixture should be put in a glass vessel, and kept of a gentle heat by standing near the fire or in warm water all night, and repeatedly stirred with a glass rod or tube. When the solution is complete, it is diluted with a thousand parts of water. One measure of this solution is put into a graduated tube of glass, and oxygenated liquor is added, until the colour of the indigo is completely destroyed, and the strength of the oxygenated liquor is ascertained by its power in discharging the colour.

Mr. Rose has recommended a method which is better adapted for general use; which is, "to have small measures properly proportioned to each other, and when the liquid is strong, to prevent waste of the indigo liquor prepared as above, and a tedious repetition of measures, let a small measure of the liquor to be tried be put into a measure containing 24 of the same measures of water (it then becomes diluted to a twenty-fifth part); to a measure of this diluted liquor add as many measures of the blue test as it will discharge, which multiplied by 25, gives its whole strength. It will be proper to have a measure of five for the sake of dispatch, in adding the blue test liquor. It is necessary that the experimenter should sit low enough to view his measures horizontally, in order that they may not be overfilled, otherwise he may be deceived.

Great care should be taken in the choice of the indigo and the vitriolic acid employed, for unless the indigo is of the Guatimala kind, or best East India, and the vitriolic acid highly concentrated and pure, the colour produced will be a greenish brown, instead of a bright blue.

Mr. Chaptal has employed the oxygenated muriatic acid to the purpose of bleaching paper, both by applying it to the rags before worked down, and to the pulp or paste; he also restored the white to prints discoloured by time, by immersing them in the oxygenated muriatic acid liquor, or exposing them to the action of its vapour. And several patents have been granted in this kingdom for bleaching pulp or paper, amongst which Messrs. Clement and George Taylor, of Maidstone, in Kent, have obtained one for bleaching the pulp, by inclosing it with a liquor of oxygenated muriate of pot-ash, in a vessel resembling a churn, eight feet diameter at the great end, three feet four inches diameter at the little end, and two feet ten inches in the clear. This vessel revolves upon an axis at each end, and the pulp, by this motion, and projecting parts within the vessel, is constantly exposing fresh surfaces to the liquor, till the whole pulp is sufficiently whitened.

Mr. Bigg, of Iping, in Sussex, has since obtained a patent for bleaching paper, and restoring to whiteness damaged or mildewed paper, by exposing in close wooden vessels paper, in quantities of six or eight sheets together, on wooden frames

placed at small distances from each other, to the action of oxygenated muriatic gas, and after the paper is taken out, pressed, and dried, previous to its being sized, wetting it in a solution of alum water.

Another method he proposes, is by wetting and soaking the paper in oxygenated muriatic acid liquor, till it is properly bleached; after which it should be well pressed and dried, and wet out in the alum water, as in the other process.

A patent has likewise been granted to Mr. Elias Carpenter, of Bermondsey, London, for a method of bleaching paper in the water leaf or sheet, and sizing it without drying; he uses for this purpose a stout deal box or case, which must be carefully closed, and capable of confining water or steam within this. The paper to be bleached is to be hung on strips of glass, about 15 inches long, placed in grooves within the box, about four sheets on each strip; the paper is taken for this purpose when pressed in the packs in its wet state, and when the box is filled and closed, it is exposed to the action of oxygenated muriatic gas for eight or ten hours, and when sufficiently bleached, sized with a preparation made from one hundred weight of pieces of skins boiled in water and strained, then fourteen pounds of alum, seven pounds of white vitriol, and one pound of gum arabic added; these ingredients will make size enough for about 50 reams of foolscap paper; the paper when sized and pressed, is finished in the usual way. To prevent the noxious qualities of the gas to the workmen, he directs a solution of pot-ash in water to be placed at the bottom of the bleaching box, to absorb the elastic vapours which would otherwise affect them on opening the box.

Mr. Tennant of Glasgow, subsequent to the patent granted him for his bleaching liquid, has obtained a patent for preparing the oxygenated muriate of lime in a dry form, by which means bleachers may be cheaply and conveniently supplied with it by him, and save much of the trouble, expence, and hazard which attend the preparation of the former bleaching liquor.

To bleach silk from its natural gummy state, whether in skain or manufactured, it should be put into a thin linen bag, and thrown into a vessel of boiling water in which good white soap has been dissolved; the silk should boil two or three hours in this liquor, and the bag of silk frequently pressed with a stick, and turned, so that the gummy matter may separate from it, and rise to the surface of the liquor, from whence it should be skimmed off, and thrown away; the bag should then be taken out, and if it contains silk goods, they should be well washed in clean cold water, to prepare them for printing or dyeing; but if the bag contains silk in the skain, after it has been well washed in clean water, beaten, and slightly wrung, it may be put the second time into the copper vessel, filled with cold water mixed with soap, and a little indigo blue, if you wish it tinged a little of the blueish hue.

The silk, when taken out of the second water, should be wrung hard with a wooden peg, to press out all the liquor; then shaken, to separate the threads; then suspended on poles, in a close room or stove where sulphur is burnt, which improves the whiteness of the silk.

Woollen cloths or stuffs may be bleached and made white by soap and water; by the vapour of sulphur; or by chalk, indigo, and sulphuric vapour. In the first case, after the stuffs have been cleaned at the fulling mill, they are again worked in warmish soap and water, to render them whiter, and afterwards washed in clear water and dried; in this state they are fit for dyeing any light colours.

To destroy or remove the reddish hue arising from boiling printed cottons in madder decoctions, which prevents the

printed colours appearing to advantage, the goods are usually boiled for some time in bran and water, and then exposed to the air, by laying them on the grass, and throwing upon them clear water from time to time. Mr. Grimshaw, in the year 1796, obtained a patent for clearing printed goods coming from the madder copper, by using the grains after brewing malt liquors, instead of bran; the plan he recommends is, that the grains should be previously sour, and that three or four bushels thereof, more or less, according to the colour of the cloth, should be put into a copper of hot water, containing 200 gallons or upwards, and four or five pieces of the printed cotton goods then immersed therein, and worked over a winch backwards and forwards, for ten

or fifteen minutes; the pieces are then taken out of the copper, and well washed in clear water, and laid straight upon the ground for two or three days, till the parts which should be white become clear. The same liquor, with the addition of a few grains, will serve to clear other printed goods, till the whole number wanted to be cleared have been completed; a sufficient quantity of clear water being added to replenish what has been absorbed by the goods, or evaporated in boiling. After either of the operations above-mentioned, the immersion of the printed goods in dilute oxygenated acid, will answer the purpose of the exposure to the air.

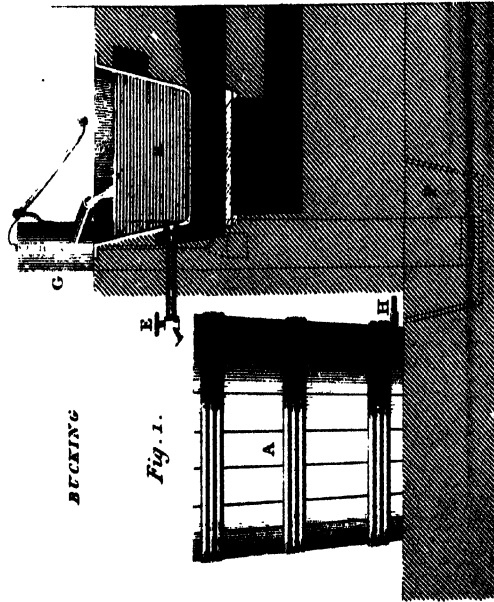


Fig. 1.

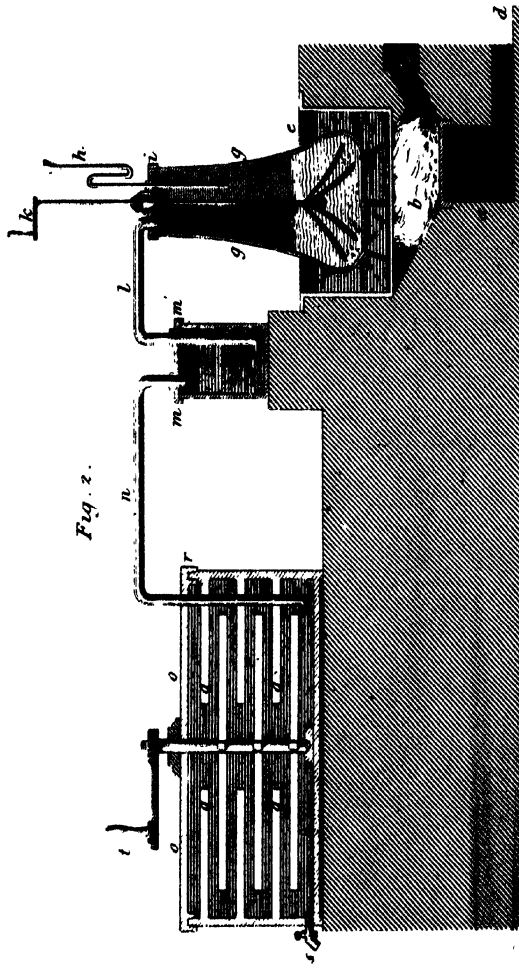


Fig. 2.

OXI-MURLATIC ACID

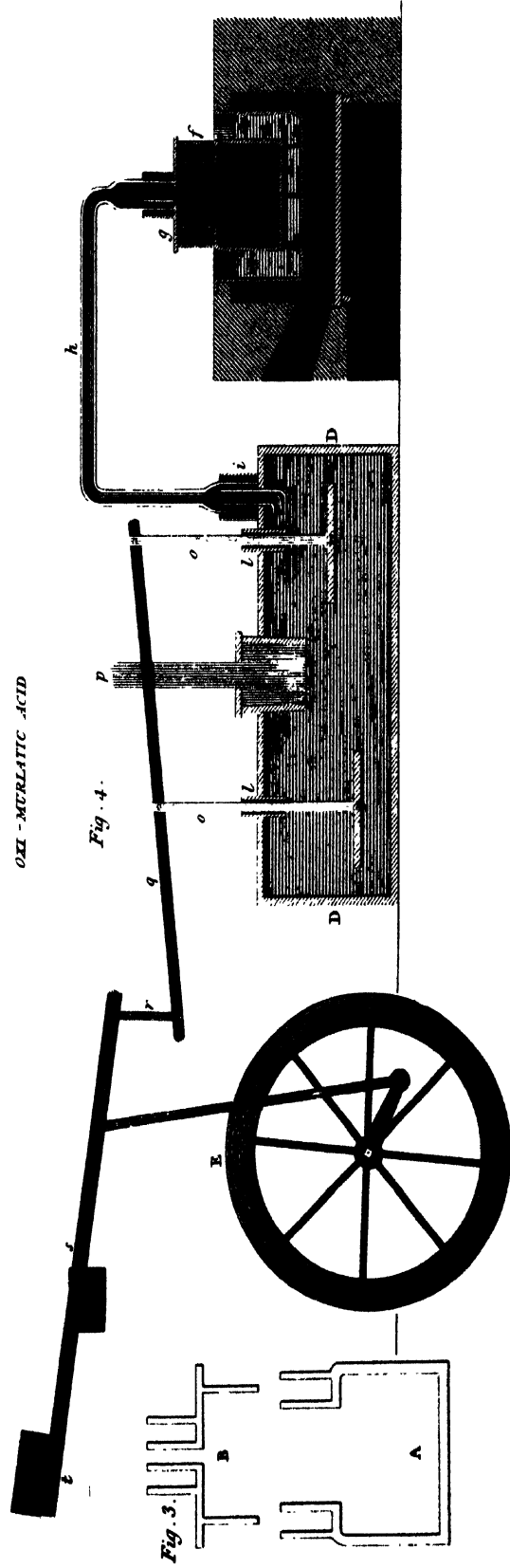


Fig. 3.

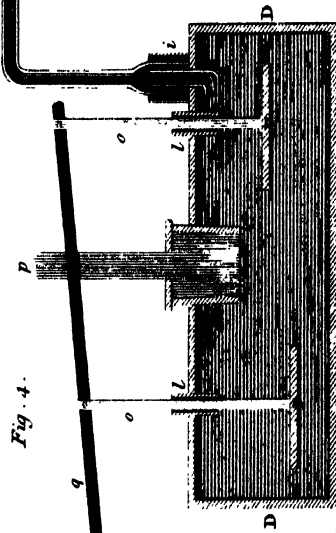


Fig. 4.

BLEACHING.

WASHING & CLEARING

Fig. 2.

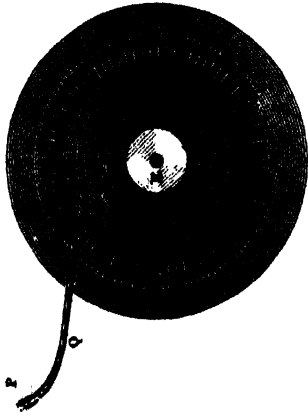


Fig. 1

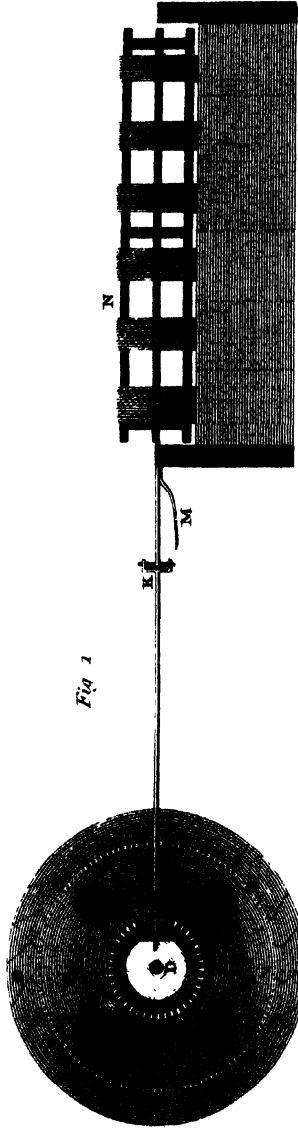


Fig. 3

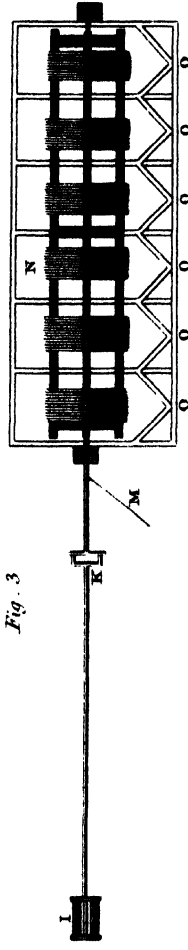


Fig. 5

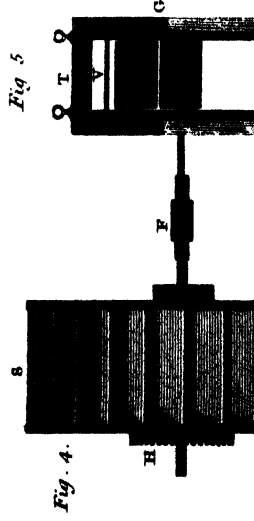


Fig. 4.

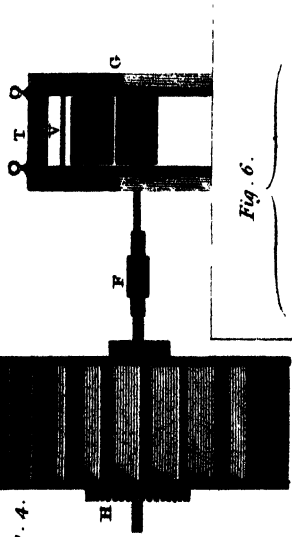


Fig. 7

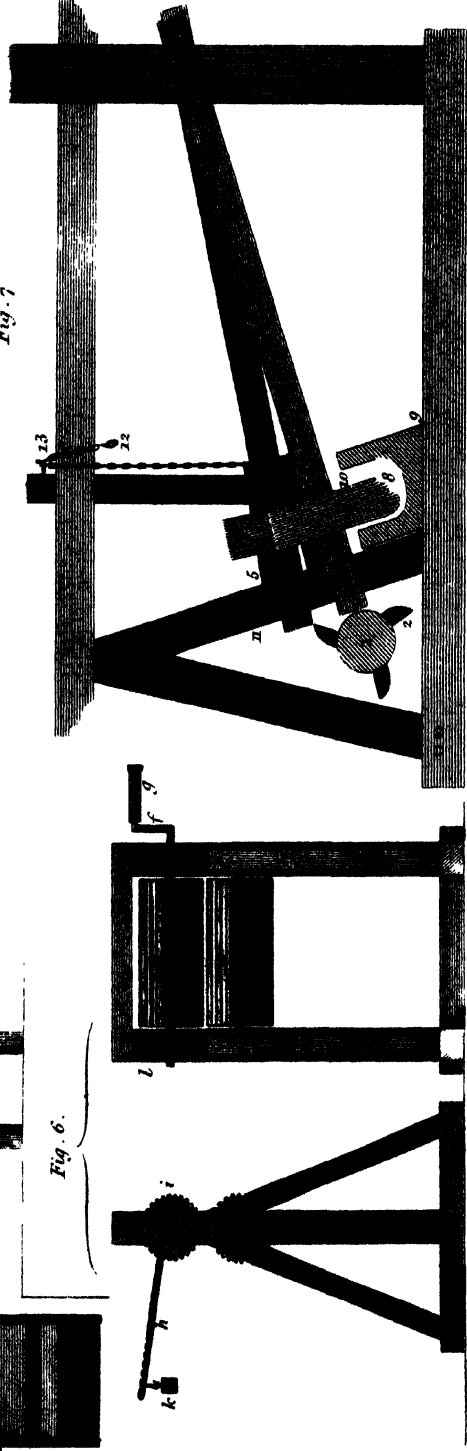
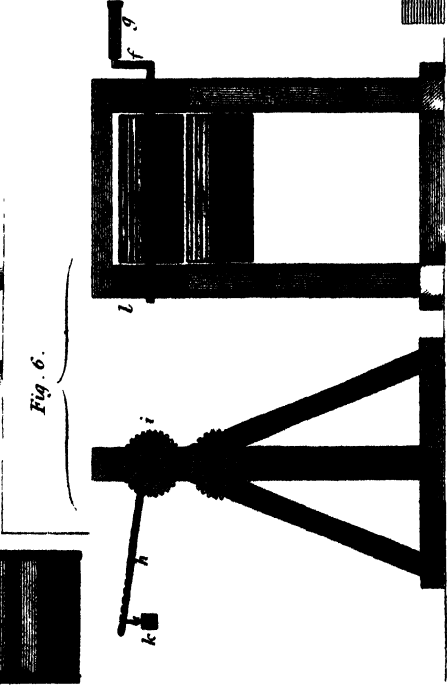


Fig. 6.



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Engraved by Wilson Lowry

BLEACHING.

PLATE III.

DRYING.

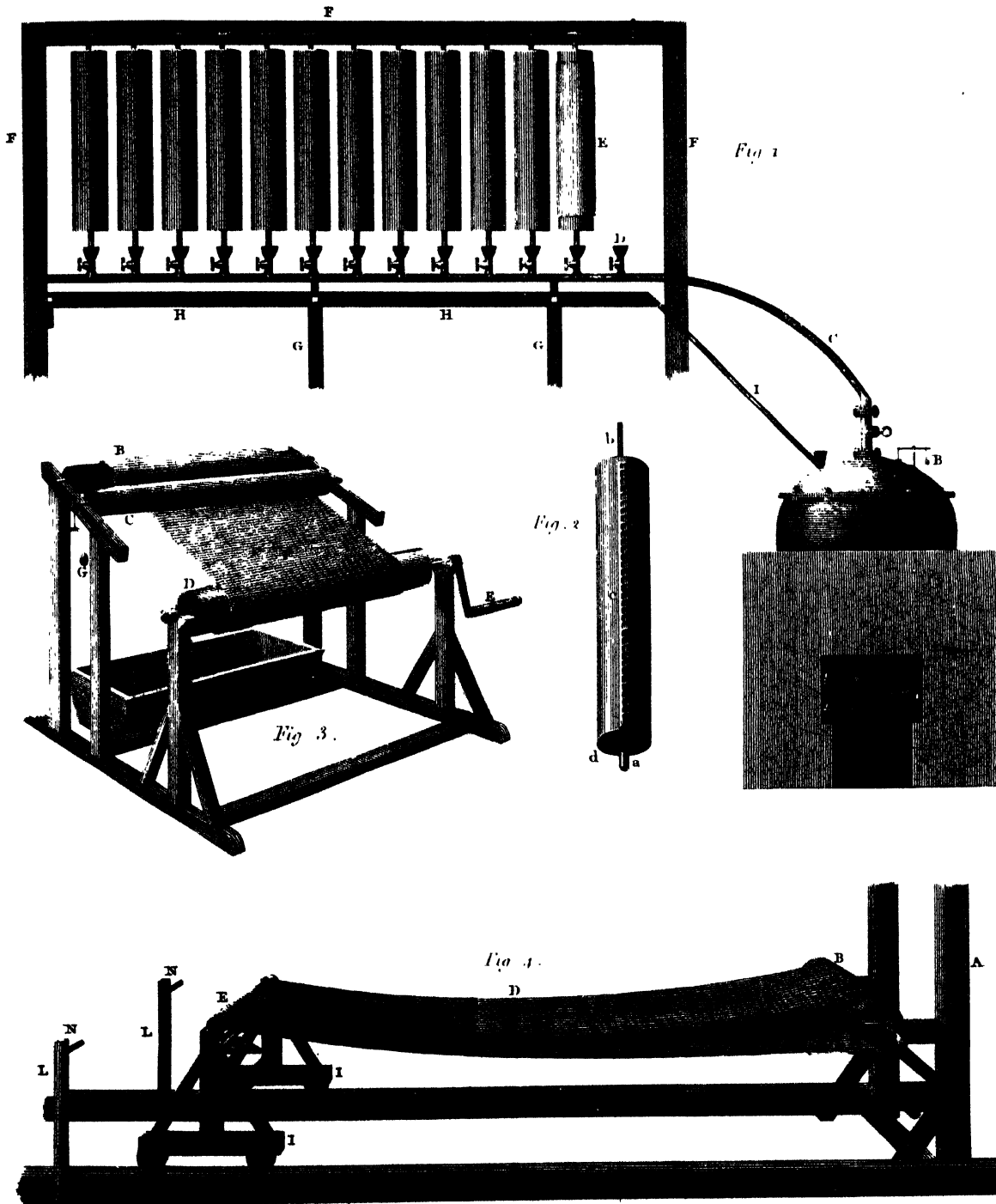


Fig. 1.

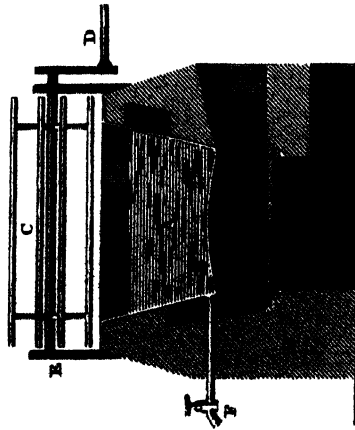


Fig. 2.

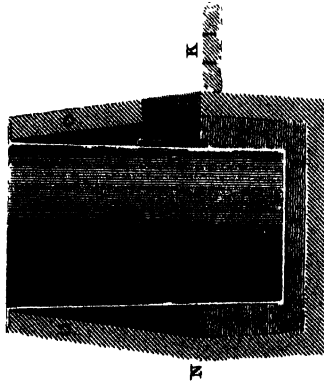


Fig. 3.

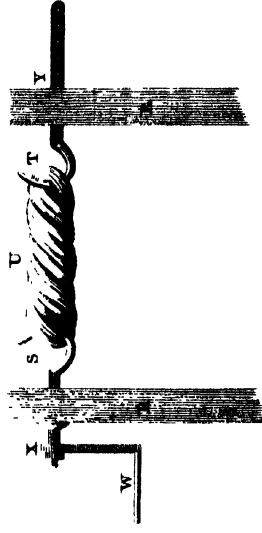


Fig. 5.

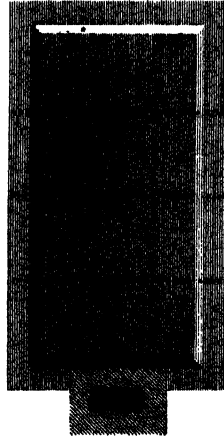


Fig. 4.

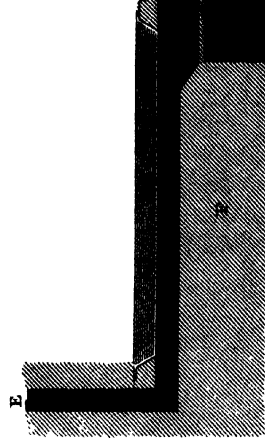


Fig. 6.

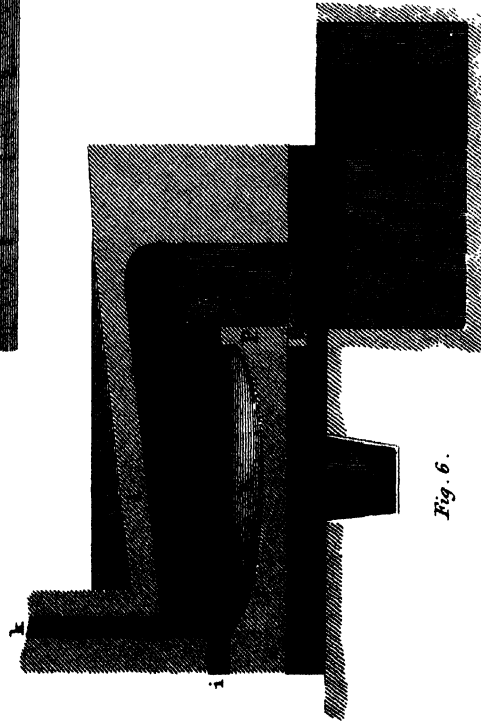
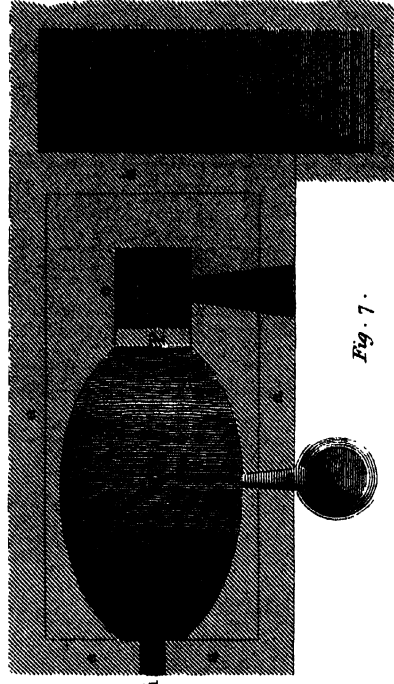


Fig. 7.



Blowing of Glass

BLOWING OF GLASS, one of the methods of forming the divers kinds of work, in the glass manufacture. It is performed by dipping the end of an iron ponteglio, or blow-pipe, in the melted glass, and blowing through it with the mouth, according to the circumstances of the glass to be blown.

BLOWING of tin, a term used by the Cornish miners for the fusion or reduction of tin-ore to the metallic state, after having been roasted to get rid of the sulphur and arsenic.

BLOWING Machine, is used in metallurgical operations on a great scale, for the purpose of exciting combustion in furnaces appropriated for the smelting and reducing of ores.

The history and improvement of machinery of this nature have kept pace with the other branches of our national manufacture, and, in many instances, may be justly said to have gone beyond them.

In the smelting of lead and tin ores, the size and powers of the blowing machine have been less a subject of alteration and improvement, than those used at furnaces and works where iron ore is smelted.

The natural fusibility and easy volatilization of the former metals, in temperatures beyond a bright red heat, have prescribed the size of the furnace, the measure of the blast, and the nature of the fuel.

In the manufacture of copper, air-furnaces are generally used, except where precipitated oxyd of copper is revived in small blast-furnaces, resembling those called cupolas, used at iron founderies.

The construction of a lead smelting machine, or what is commonly called a "Lead Mill," is extremely simple. A water wheel is erected in the middle of a square building. To the shaft of this wheel are attached four small wheels of cast iron, about 18 inches diameter. Four pairs of bellows, two pairs on each side of the shaft, are placed at equal distances, and supported upon a strong framing of wood. As the water wheel shaft revolves, the small wheels are carried round, and alternately, or two and two together, depress the extremity of a lever attached by an iron chain to an equipoised beam, the descent of this lever elevates the opposite end of the beam, to which is also attached, by means of another iron chain, the upper or moveable surface of the bellows. The blast produced in this way is in general less,

much inferior in point of either quantity or density to what is found necessary at iron furnaces. The bellows in common measure 10 feet in length, and 5 or 6 feet across the breach, moving about 30 strokes per minute.

In the manufacture of iron it has always been, particularly since the introduction of pit coal, the unceasing object of the iron-maker to improve his blowing apparatus; for uniformly he has found, that in proportion as he can raise air, and make it enter the furnace, so will his weekly quantity of metal be increased.

In the early history of this interesting manufacture, when charcoal of wood was the matter of fuel made use of, the affinities betwixt the latter and the ore were established with more facility. Small furnaces, called bloomeries, were sufficiently large, and deemed of profitable capacity, if they produced a bloom or two of iron per day, of 90 to 120 lbs. each.

Hand bellows, and what were called fuel blasts, were sufficiently large for the minor operations. After the general introduction of the refinery furnaces, and the division of the manufacture into the making of pig iron, and the refining of this into bar or malleable iron, the advantages of a powerful blast were immediately perceived. Water wheels, working two pairs or more of leather bellows, were found to produce powerful effects, and, in consequence, almost every situation that presented a command of materials and a waterfall, became the seat of an iron-mill.

The simple mode of blowing furnaces by means of a trompe, was at the same time introduced; but in general it was found, that much greater advantage could be derived from the descent of water upon a wheel, either as to density or quantity, than by means of the best constructed trompe.

The use of water wheels and leather bellows continued general throughout the iron business, until the principles and mechanism of the steam engine were established upon unerring grounds. This wonderful invention was soon applied with the happiest effect in many situations rich with mineral treasures, but to which nature had denied the advantage of water sufficient to turn machinery. Cylinders, composed of wood, firmly jointed and hooped, were first introduced as a substitute for leather bellows: these were soon after replaced by bored cylinders of cast iron; and with

with this great discovery and application of the art of casting, the blowing machine assumed a general and well-proportioned form.

This took place nearly 40 years ago, and continued with a few temporary deviations until the introduction of Bolton and Watt's highly improved engine. The following may serve for an outline of the old blowing steam engine.

A steam cylinder, working with atmospheric pressure from 3 to 7 lbs. upon every square inch of the area of the piston. The diameter of the cylinder for one furnace varied from 25 to 36 inches, and for two furnaces from 36 to 50 inches. Upon the opposite of the main or working beam, sometimes at equal, and sometimes at unequal distances from the centre, was placed the air-pump or blowing cylinder. This was, in common, equal to four or five times the area of the former; and, with the small working power of the steam cylinder, seldom condensed the air beyond $1\frac{1}{2}$ to $1\frac{3}{4}$ lbs. per square inch. The air-pump was commonly constructed open below, as may be seen in *Plate II. fig. 1. (Chemistry)*. The plan was sometimes deviated from, and the cylinder inverted. The blowing piston was loaded with weights, and the air expressed by its descent. In this mode of working, the act of the steam piston, descending in vacuum, raised the air-pump piston loaded with weights. Upon the return of the stroke, or while the steam piston ascended in the cylinder, this piston loaded with weights sunk the whole length of the stroke, and by means of this loading, proportioned to the powers of the engine, forced the air either into the regulator or the furnace.

Above, or parallel to the air-pump, was placed the regulating cylinder, as may be seen in the plate above mentioned. This had a valve of communication, which opened every stroke the engine made, and admitted the whole discharge of air. The piston of the cylinder, frequently called the fly piston, was loaded with weights, and kept constantly vibrating; so that when any deficiency of pressure arose from the remitting action of the air-pump piston, the blast was comparatively equalized by the pressure of the fly piston upon the included air. The size of this cylinder was generally in the proportion of 9 to 6 of the air-pump.

The chief objections to this mode of blowing, even when in universal use, were founded upon the great inequality of the blast, and a very considerable waste of air that took place at the *snort*, or safety valve, to prevent the fly piston being blown entirely out of the cylinder. The snort was an opening made in the top of the air-pump cylinder, on which rested a heavy iron valve, faced with leather stuffed with wool; this was, by means of an upright iron rod, attached to a lever, which ran across the top of the regulating cylinder. As soon as the fly piston arose to a certain height, a block of wood, or other contrivance, lifted the one end of the lever, and along with it the valve, to a certain height, and permitted a quantity of the densest air to escape, sufficient to insure the safety of the piston. Notwithstanding these precautions, many accidents and stops ensued; the breaking of a pin, or the losing of a key, frequently ejected the piston from its cylinder, though loaded with several tons of weight.

Some iron masters, more ingenious than others, contrived to take the spare or waste air from the snort, to receive it in an inverted chest above water, and blow to its extent smithy and finery fires. Endeavours of this kind to husband and economise air, raised and condensed at a great expence, were sufficient proofs that a method was still wanting to complete the blowing machine, to render its motions steady and uniform, and to equalize the density of the blast throughout the whole stroke.

This was completely accomplished by inverting large chests, or cylinders, in cisterns of wood, stone, or iron. The space betwixt the inner and outer cisterns was constructed of sufficient capacity to oppose to the expansive force of the blast a column of water of equal or superior resistance.

This invention was called the water blast, water pressure, water regulator, &c. The dimensions differed materially from from each other; this circumstance being much regulated by convenience, opinion, and the size of the engine.

Plate XIV. fig. 1. (Chemistry) represents a ground plan of a very capacious water regulator, sunk in the ground, and built of stone and bricks.

A, the inverted chest made of plates of cast iron, 40 feet long, 12 feet wide, and 12 feet high. The square superficies of this chest is equal to 480 feet, and its cubical contents are 5760 feet. Its weight will amount to nearly 30 tons.

B, the opening to which the air-pipe is attached; 2 feet diameter.

CCCC, open space betwixt the inverted chest and stone cistern, for the column of water to ascend; $3\frac{1}{2}$ feet wide.

DDDD, stone or brick-work, of which the great cistern is built. This work requires to be well jointed, as the motion of the water has a great tendency to open the spaces betwixt the stones. This cistern is 47 feet long, 19 feet broad, and 14 feet high; its cubical measurement amounting to 12,500 feet, and capable of containing 93,500 gallons wine measure.

EEEE, an opening of one foot in breadth left in the middle of the building. This is compactly filled with well trod clay, called puddling, and prevents the escape or circulation of water through the building. Beyond this the common building extends to a sufficient thickness to give general security to the whole.

Fig. 2. is a cross section of the water regulator at B, *fig. 1.* The letters in this view correspond with those in the plan.

F, the blast pipe from the cylinder entering the chest, and branching to the two blast furnaces.

GG, large hewn stones, on which the chest is supported, about two feet from the bottom of the cistern, at intervals of six feet from each other.

H, loading of hewn stone, which for this cistern requires to be equal in all to 90 tons. If the chest weighs 30, then 60 tons of loading will be requisite. This is supposing that the power of the blowing machine is calculated to press equal to 3 lbs. upon every square inch, which many of them are constructed to perform.

To comprehend distinctly in what manner the water regulator performs its functions, and upon the supposition that the compressing power of the engine is equal to 3 lbs. upon every square inch, we shall suppose the engine at rest, and water introduced into the regulator, till it rise to the level of the dotted line *b*, 5 feet from the lower edge of the chest, and 7 feet in total depth of water. As soon as the engine is set to work, the compression of the air immediately sets the water in motion; every stroke making the water rise in the space CC, and proportionally falling towards GG, in the interior of the chest.

When the inverted chest becomes filled with air, and the condensation has reached the maximum of the power of the blowing machine, the water will be found elevated $3\frac{1}{2}$ feet to *i*, and the gauge will exhibit a depression in the interior of the chest, from *b* to *k*, $3\frac{1}{2}$ feet, making in all 7 feet from *k* to *i*.

At every turn of the engine stroke, the water maintained at *i* falls a few inches, and elevates itself above *k* in the in-

terior of the chest, a similar height. This description takes it for granted, that the spaces CC are equal to the area of the inverted chest; so that every inch of water forced out of the chest adds exactly one inch to the height of the column.

A blowing machine, capable of blowing to purpose two blast furnaces, ought to have the inverted chest of the regulator equal to three or four hundred square feet of area. There cannot arise any error from having this large enough; the want of space and capacity frequently proves a real detriment.

In calculating the proportions and dimensions of water regulators in general, the principle is, to allow the space around the inverted chest equal in point of superficial measurement to the area of the interior of the chest, that the descending column of water may displace no more in the perpendicular ascent, than it is itself absolutely depressed.

If the area or space in which the water rises and falls, is only equal to half the area of the inverted chest, then for every foot of water which is depressed in the bottom of the chest, a column of two feet will be raised and maintained on the outside. On the contrary, if the outside space for water be equal to twice the area, then every foot of water depressed in the chest will only elevate the external column six inches.

It will appear evident from these general facts, that a considerable latitude may at any time be assumed in constructing the water regulator, particularly in old established works, where local circumstances and convenience confine its situation to one spot.

Where it is not inconvenient to use a high perpendicular column of water, the inverted chest may be increased one half, double, or even triple the superficial measurement of the outside space; so that if the power of the blowing machine is equal to 3 lbs upon the square inch, the water in the chest will be depressed $3\frac{1}{2}$ feet nearly, and raised in the perpendicular column 5 feet 3 inches in the first, 7 feet in the second, and $10\frac{1}{2}$ feet in the last case. This plan to suit former establishments may be adopted with considerable modifications, always keeping in mind, that every foot of area gained upon the surface of the water is a material acquisition to the equalizing powers of the regulator.

One imperfection attends this want of equilibrium on the two spaces for the action and re-action of the water.—Whatever space the waters would fall, at the return of the stroke, supposing the inside and outside columns exactly balanced, would in this case be increased one half, double, or triple.

Again, where situation does not admit of the perpendicular column being raised beyond, or not even to the extent of the depression, that takes place within the inverted chest, and where an additional space cannot be procured for an increase of its diameter, an inverted chest of much less height than common may be used, loaded with a material of great weight, such as iron. The water in that case would distribute itself over the surface of the chest, instead of rising in perpendicular height.

One serious objection, however, is made to chests or cylinders, where the eduction pipe approaches within a short space of the surface of the water; namely, water rising in the pipes, and being conveyed along with the air into the furnace. This may take place in two ways; by an insensible and uniform discharge of water into the furnace, making the blast at the tuyere visible, like the respiration of the human body in a frosty day; or in quantity, threatening utter destruction to the furnace and buildings. The former is occasioned by the air from the eduction pipe, at the com-

mencement of the stroke, impinging violently upon the surface of the water, and raising a portion of it in the state of spray. This is speedily dissolved or entangled in the mass of condensed air before the return of the next stroke, and becomes expressed along with the blast into the furnace. The other hazardous consequence is occasioned chiefly by undulation in the column of water, when the blowing machine is, by derangement or accident, working under its proper power or number of strokes. In these cases, when the pause at the end of the stroke is prolonged, an exhaustion sometimes takes place in the air-pipes, the water rises and is carried in a stream through the blow-pipe into the furnace.

The same casualties may more readily occur, if the surface of the water is upon a level, or nearly so, with the tuyere.

In judicious erections this is most carefully avoided; the surface of water in the inverted chest or cylinder is kept at least 8, 9, and 10 feet under the level of the tuyere even at the last period of return, when the water has risen to its greatest height within.

This very proper precaution ensures an advantage of much importance. A large space is obtained betwixt the top of the chest and the depressed surface of the water; this becomes a spacious reservoir for the condensed air, and, by generating a considerable portion of elasticity, prevents any violent perturbation upon the water at any period of the stroke. The increased distance betwixt the surface of the water, and the pipe which conducts the air from the cylinder, has a complete tendency to prevent the elevation of the aqueous particles, and always ensures a quantity of air comparatively free from moisture.

Upon the principles formerly noticed, it is possible to construct a blowing apparatus of this nature, wherein there could be little or no visible motion in the perpendicular column of water even with the same engine.

Let us suppose a machine of this nature at work, with an accurately balanced column of water, the fall of which, at the return of the stroke, was equal to 12 inches. It is evident, that if the outside space was enlarged so much over its surface as to contain this foot of water, without adding any perceptible height to the column; that included within the chest would, at the return of the stroke, being fed from a more capacious limb, rise a foot, without any sensible diminution taking place in the perpendicular height of the external fluid. It is equally obvious, in this as in every case with water regulators, that the rise and fall of the inside column of water will remain the same, under every modification and form, while the pace and powers of the engine remain the same.

The application of water regulators to blowing machines was soon followed by an attempt to further improvement, by the introduction of the air-vault; the principle of which was to form a receiver of such capacity, that the elasticity or spring of the condensed air would be sufficient to express and equalize the blast during the return of the stroke.

To effect this, an immense magazine was requisite; to erect which of any metallic substance would have been ruinously expensive, and, if constructed of wood, insufficient for retaining the air. It became therefore requisite to try the experiment upon building, or by excavation from the solid rock. In both these ways has the air-vault been tried, and found to produce an excellent effect, as to equalizing the density of the blast; but it has been conceived with such indifferent consequences as to quantity, that the plan is for the present given up.

Air-vaults were constructed both at the Clyde and Muirkirk iron works in Scotland, and a constant current of air produced; but nearly one half the quantity lifted by the air-pump escaped through the walls and arches of the building. This was at any time made visible by rubbing soapy water upon the external walls.

At Devon iron works in Scotland, an air-vault was excavated from the solid rock, 72 feet long, 14 feet wide, and 13 feet high; equal to 13,000 feet of cubical measurement. This immense excavation was made comparatively air-tight, by caulking the seams and fissures of the rock, plastering and then covering the whole with alternate layers of pitch and clove wove paper.

This was the most perfect experiment ever tried upon the air-vault; and if an opinion is to be formed of the perfection of the apparatus by the quantity of iron at one time manufactured, a very trifling portion of air indeed must have been lost.

It has been frequently noticed in Scotland, that at works where the materials were in any degree similar, 3000 to 3500 cubical feet of air per minute will, in the course of a week, produce from 30 to 35 tons of pig iron, whatever may be the density at which it is thrown into the furnace.

The Devon furnace at one time averaged 33 tons weekly for 9 months running, and consumed of air, per data furnished by Mr. Roebuck in his paper published in Nicholson's Journal, vol. iv. nearly 3400 cubical feet per minute, under a pressure of $2\frac{1}{2}$ lbs. per square inch. Notwithstanding this powerful demonstration, strong prejudices were entertained to its disadvantage; and many believed, that had any other mode of regulator been attached to the blowing machine, abundance of air would have been obtained to have blown two furnaces equally well. That this idea was incorrect, may be easily gathered by calculation from the area of the air-pump, the length of the working stroke, and the number of strokes per minute, all of which are particularly stated by Mr. Roebuck.

For the general construction of an air-vault formed by building, see Plate XV. (*Chemistry*.)

Fig. 1. is a section of the vault constructed under the bridge-house, or place where the materials are proportioned, previously to their being thrown into the furnace. One half a blast furnace outline, is seen as connected in point of situation and blast to the air magazine.

A, the termination of the blast pipes that convey the air from the blowing cylinder into the receiver, 3 feet diameter; the length depends upon the contiguity of the engine to the vault.

B B B B, four vaults, 13 feet wide each, 25 feet deep, and 10, 11, 12, and 13 feet high to the springing of the arches; total height to the crown of the arches, $16\frac{1}{2}$, $17\frac{1}{2}$, $18\frac{1}{2}$, and $19\frac{1}{2}$ feet. These cells communicate with each other by arched openings in the cross-walls, which may be distinctly seen in the ground plan at L.

C C, the education pipes that carry the air to the furnace; 18 inches diameter.

D, end view of the range of laying pipes at the tuyere of the furnace. The dotted lines betwixt D and C are meant to represent the horizontal range of the pipes.

E, part of the outline of a blast furnace to shew its proper situation to the air vault.

F F F F, floor of the respective vaults, composed of a mixture of two parts of boring dust, two of fine riddled lime, and one part of fine roasted iron stone, mixed up into

plaster with water containing a considerable portion of salt.

G G, end walls of bricks or stone, four feet thick.

H H H, lining of brick-work, built in the most accurate manner, with fine riddled mortar, and run every second or third course with mortar made thin and very liquid. These walls are two feet and a half in thickness, are carefully plastered, and afterwards covered with several layers of strong paper and pitch, to prevent the escape of air. The roofs of the vaults are finished in the same manner.

I, door arch into the vaults; entrance obtained by means of a ladder or wooden stairs suspended within.

K, space above the arches, filled with rubbish, to prevent any spring, and to raise the floor to the level of the furnace top.

L, the range of the floor, or acclivity to the furnace mouth.

Fig. 2. is a ground plan of the bridge-house containing the air-vaults, and exhibits one half the ground plan of the furnace through the centre of the tuyere arches.

B B B B, corresponding to the same letters in the elevation.

C C, pipes for taking off the blast into the furnace.

D, corresponding to the same letter in the section.

E, main pillar of the furnace, same as E in the section.

G G G G, and H H H, correspond with the same letters in the elevation.

I, square for receiving the furnace hearth.

K, part of the ground view of the hearth, and the approaching blast pipes.

L L L, openings of the cross arches, which communicate the vaults with each other.

The cubical contents of a vault, constructed according to these dimensions, will amount to 20,000 feet.

In general, it may be remarked upon the construction of the blowing machine, that since the period of the introduction of Mr. Watt's engine, the air-pump, or blowing cylinder, has been constructed so as to discharge a cylinder full of air every ascent and descent of the piston. This, instead of travelling 4 to 5 feet per stroke, more generally moves 8 feet; and the number of cylinders per minute are seldom under 24.

Formerly, in the common atmospheric engine, the movement of the piston from top to bottom, and back again, produced only one cylinder full of air from the air-pump, and the number of cylinders discharged per minute seldom exceeded 16. A steam cylinder of 40 to 44 inches diameter, and an air-pump of 6 feet diameter, the piston moving about 5 feet per stroke, were deemed sufficient in the construction of a blowing machine for two blast furnaces. The quantity of air pumped up and thrown into the furnaces by such an engine seldom exceeded 3000 cubical feet per minute. This, and even a larger quantity, is now thrown into one furnace, and the produce by such means increased from 15 to 35 tons weekly.

The first set of tables following are calculated to shew the quantity of air that would be discharged by blowing cylinders of various diameters, the length and number of the strokes being given.

The second set, to shew what diameter of blowing cylinder is requisite, with a given steam power, to raise the air to a certain density per square inch. See ENGINES, WATER REGULATOR, and REGULATING VAULT.

BLOWING OF GLASS

TABLE I. of Blowing Cylinders, their Capacity, Area, and Quantity of Air discharged by a Four-Foot Stroke, &c.

Di- ameter in Inch.	Area in Circular Inches.	Area in Square Inches.	Capacity of a Cylinder in Cubic Feet.	Air discharged at the Rate of 5 Cylinders per Minute.	Air discharged at the Rate of 10 Cylinders per Minute.	Air discharged at the Rate of 15 Cylinders per Minute.	Air discharged at the Rate of 20 Cylinders per Minute.	Air discharged at the Rate of 25 Cylinders per Minute.	Air discharged at the Rate of 30 Cylinders per Minute.	Air discharged at the Rate of 35 Cylinders per Minute.	Air discharged at the Rate of 40 Cylinders per Minute.	Air discharged at the Rate of 45 Cylinders per Minute.	Air discharged at the Rate of 50 Cylinders per Minute.
36	1296	1017.8784	28.3744	1413.7200	1130.9760	848.2320	706.8600	565.4880	424.1160	339.2928	281.7440		
37	1369	1075.8670	29.8670	1493.3500	1194.0300	896.0100	746.6750	592.3400	448.0050	358.4040	298.6700		
38	1444	1134.1176	31.5032	1575.1600	1260.1280	945.0960	787.5800	630.1280	472.5480	378.0384	315.0320		
39	1521	1194.5934	33.1831	1659.1550	1327.3240	995.4930	829.5775	663.6620	497.7465	398.1972	331.8310		
40	1600	1257.0400	34.9055	1745.2750	1396.2200	1047.1656	872.6375	698.1100	523.5825	418.8650	349.0550		
41	1681	1320.2574	36.6738	1833.6900	1466.9520	1100.2140	916.8450	733.4760	550.1020	440.0856	366.7380		
42	1764	1385.4456	38.4834	1924.1700	1539.3360	1154.5020	962.0850	769.0680	577.2510	461.8008	384.8340		
43	1849	1452.2046	40.3390	2016.9500	1613.5600	1210.1700	1008.4750	806.7800	605.0850	484.0680	403.3900		
44	1936	1520.5344	42.2370	2111.8500	1689.4800	1267.1100	1055.9250	844.7400	633.5550	506.8440	412.3700		
45	2025	1590.4350	44.1787	2208.9350	1767.1480	1325.3610	1104.4765	883.5740	662.6805	530.1444	441.7870		
46	2116	1661.9064	46.1640	2308.2090	1846.5600	1384.9200	1154.1000	923.2800	692.4600	553.0680	461.6400		
47	2209	1734.9486	48.1930	2409.6500	1927.7200	1445.7900	1204.8750	963.3600	722.8950	578.3160	481.9300		
48	2304	1809.6160	50.2656	2513.2800	2010.6200	1507.9680	1256.6400	1005.3120	753.9840	603.1872	502.6560		
49	2401	1885.7545	52.3818	2619.0900	2095.2720	1571.4540	1309.5450	1047.6360	785.7270	628.5816	523.8180		
50	2500	1963.5000	54.5416	2727.0800	2181.6640	1636.2480	1363.5400	1090.8320	818.1240	654.4992	545.4160		
51	2601	2042.8254	56.7451	2837.2550	2269.8040	1702.3530	1418.6275	1140.9020	851.1760	680.9412	567.4510		
52	2704	2123.7216	58.9944	2948.2200	2358.5760	1768.9320	1474.1100	1179.2800	884.4600	707.5728	589.6440		
53	2809	2206.1886	61.2850	3064.1500	2451.3200	1838.4900	1532.0750	1220.6600	919.2450	735.3960	612.8300		
54	2916	2290.2264	63.6173	3180.8650	2544.6920	1908.5190	1590.4327	1272.3410	954.2595	763.4076	636.1730		
55	3025	2375.8350	65.9954	3299.7700	2639.8160	1979.8620	1649.8850	1319.9080	989.5310	791.9418	659.9540		
56	3136	2463.0144	68.4017	3420.5350	2736.4280	2052.3210	1710.2075	1363.2140	1026.1605	824.9284	684.1070		
57	3249	2551.7646	70.8823	3544.1150	2835.2920	2126.4690	1772.0575	1417.6600	1063.2345	850.5876	708.8230		
58	3364	2642.0856	73.3913	3669.5650	2935.6520	2201.7490	1834.7825	1467.8260	1100.8095	880.6956	733.9130		
59	3481	2733.9774	75.9438	3797.1900	3037.7520	2278.3140	1898.5950	1518.8760	1139.1520	911.3256	759.4380		
60	3600	2827.4400	78.5400	3927.0000	3141.6000	2356.2000	1963.5000	1570.8000	1178.1000	942.4800	785.4000		
61	3721	2922.4734	81.1798	4058.9900	3247.1920	2435.3740	2029.9950	1623.5960	1217.6870	974.1576	811.7080		
62	3844	3019.0776	83.8632	4193.1500	3354.5280	2515.8960	2096.5750	1677.2640	1257.9480	1006.3584	838.6320		
63	3969	3117.2526	86.5703	4325.3650	3462.8120	2597.1090	2162.625	1731.4060	1298.5545	1038.8436	865.7080		
64	4096	3216.9984	89.3332	4466.6600	3573.3280	2679.9960	2233.3300	1786.6640	1339.9080	1071.9984	893.3320		
65	4225	3318.3150	92.1751	4608.7200	3687.0160	2765.220	2304.3600	1843.5080	1382.6300	1106.0888	921.7540		
66	4356	3421.2024	95.0334	4751.6700	3801.3360	2850.9020	2375.8350	1900.1680	1425.4510	1140.4008	950.0850		
67	4489	3525.6606	97.9350	4895.7500	3917.4000	2938.0500	2449.8375	1958.7000	1469.0250	1175.2200	979.3500		
68	4624	3631.6896	100.8802	5044.0100	4035.3080	3026.4060	2525.2050	2017.6040	1513.2030	1210.5624	1008.8020		
69	4761	3739.2894	103.8691	5193.4550	4154.7640	3116.0730	2596.7275	2077.3300	1558.0360	1246.4292	1038.6900		
70	4900	3848.4600	106.9017	5345.0850	4276.0680	3207.0510	2672.5425	2138.0340	1603.5255	1282.8204	1069.0170		
71	5041	3959.2014	109.9778	5498.8000	4399.1120	3299.3340	2749.4450	2199.5560	1649.6620	1319.7336	1099.7780		
72	5184	4071.5136	113.0976	5654.8800	4523.9040	3392.9280	2827.4400	2261.9520	1696.4640	1357.1512	1130.9760		
73	5329	4185.3976	116.2610	5813.0500	4650.4400	3487.8300	2906.5250	2325.2200	1743.9150	1395.1320	1162.6000		
74	5476	4300.8504	119.4680	5973.4000	4778.7200	3584.0400	2986.7000	2389.3600	1792.0200	1433.6160	1194.6000		
75	5625	4417.8750	122.7187	6135.9350	4908.7480	3681.5610	3067.9675	2454.3740	1840.7805	1472.6244	1227.1870		
76	5776	4536.4704	126.0130	6301.5500	5040.5200	3780.3900	3150.7750	2520.2000	1890.1950	1512.1560	1260.1300		
77	5929	4656.6366	129.3232	6466.1600	5172.9280	3879.6960	3233.0800	2586.4640	1939.8480	1551.8784	1293.2320		
78	6084	4778.3736	132.7326	6633.6300	5309.3040	3971.9780	3316.8150	2654.6520	1990.4890	1592.7912	1327.3760		
79	6241	4901.6014	136.1578	6807.8900	5446.3120	4064.7340	3403.9450	2723.1560	2042.3670	1633.8936	1366.5780		
80	6400	5026.5600	139.6266	6981.3300	5585.0640	4188.7980	3490.6650	2792.5320	2094.3990	1675.5192	1396.2660		
81	6561	5153.0094	143.1391	7156.9550	5725.5640	4294.1730	3578.4775	2862.7320	2147.0865	1717.6692	1431.3910		
82	6724	5281.0296	146.6952	7334.7600	5867.8080	4400.8560	3667.3800	2938.9040	2200.4280	1760.3424	1469.4520		
83	6889	5410.5206	150.2950	7514.7500	6011.8000	4508.8500	3757.3750	3055.4000	2254.4250	1803.5400	1527.7000		
84	7056	5541.7824	153.9386	7696.9300	6157.5440	4618.1580	3848.4650	3137.7720	2309.0790	1847.5048	1539.8860		
85	7225	5674.5150	157.6254	7881.2700	6305.0160	4728.7620	3940.6350	3152.5080	2364.3810	1891.5048	1576.2540		
86	7396	5803.8184	161.3560	8067.8000	6453.2400	4840.6800	4033.9000	3226.6200	2420.3400	1936.2720	1613.3100		
87	7569	5944.6926	165.1303	8256.5150	6605.2120	4953.9090	4128.2575	3302.0068	2476.9545	1981.5636	1651.3030		
88	7744	6082.1376	168.9482	8447.4100	6757.9280	5068.4460	4223.7050	3378.9640	2534.2230	2027.3784	1689.4820		
89	7921	6221.1534	172.8098	8640.4900	6912.3920	5184.2940	4307.2450	3456.1960	2592.1470	2073.7186	1728.0980		
90	8100	6361.7400	176.7150	8835.7500	7068.6000	5301.4500	4417.8750	3534.3000	2650.7250	2120.5800	1767.1500		
91	8281	6503.8974	180.6638	9033.1900	7226.5520	5419.9140	4516.5950	3613.2760	2709.9570	2167.9656	1806.6380		
92	8464	6647.6156	184.6562	9232.8100	7386.2480	5539.6860	4616.4550	3693.1240	2769.8430	2264.3076	1846.0620		
93	8649	6792.9246	188.6923	9434.6150	7547.6920	5660.7690	4717.3075	3773.8460	2830.3845	2313.2640	1886.4230		
94	8836	6939.7944	192.7720	9638.6000	7709.8800	5783.160	4819.3000	3854.9100	2891.5800	2362.7448	1927.4700		
95	9025	7088.2350	196.8954	9844.7700	7875.8160	5906.8620	4922.3850	3937.9280	2953.4310	2412.7512	1968.9540		
96	9216	7238.2464	201.0626	10053.1300	8042.5040	6031.1870	5026.5650	4021.2520	3015.9390	2463.2760	2010.6160		
97	9409	7389.8286	205.2730	10263.6500	8210.9200	6158.1900	5131.8250	4105.4600	3079.0950	2514.3254	2062.7300		
98	9604	7542.9816	209.5272	10476.3600	8381.0880	6285.8160	5238.1800	4190.5440	3147.9080	2565.9012	2095.2720		
99	9801	7697.7054	213.8251	10691.2550	8553.0040	6414.7530	5345.6275	4276.5020	3207.3765	2615.8744	2138.2510		
100	10000	7854.0000	218.1666	10908.3300	8726.6640	6544.9980	5454.1600	4363.3320	3272.4090	2671.9092	2181.6660		

BLOWING OF GLASS

TABLE II. of blowing Cylinders, their Area, Capacity, and Quantity of Air, discharged by a Five-Foot Stroke.

Number of Cylinders.	Area in Circular Inches.	Area in Square Inches.	Capacity of the Stroke in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.
36	1296	1017.8784	35.3430	1767.1000	1413.7100	1000.2900	663.5700	700.6605	500.1450	424.1100	353.4302
37	1369	1075.8670	37.3337	1800.0000	1493.3100	1120.0100	933.3125	715.6400	500.0005	448.0044	373.1370
38	1444	1134.1176	39.3790	1858.9500	1575.0000	1181.3700	974.4750	787.5700	500.0850	472.5480	393.7900
39	1521	1194.5984	41.4788	2073.9100	1659.1500	1244.3400	1036.6700	829.5700	612.1820	497.7456	414.7880
40	1600	1256.6400	43.6319	2181.5900	1747.0000	1308.9500	1090.2675	872.0380	654.4785	523.5828	436.3190
41	1681	1320.2574	45.8422	2292.1100	1837.0000	1375.2600	1147.0550	916.3440	687.6330	550.1064	458.1720
42	1764	1385.4456	48.1042	2405.2100	1927.0000	1443.1200	1202.6050	962.0840	721.5930	577.2504	481.0420
43	1849	1452.2046	50.4237	2521.1850	2016.9480	1512.7120	1260.5925	1008.4740	753.3550	605.0844	504.2370
44	1936	1520.5344	52.7962	2639.8100	2111.8430	1584.3860	1319.9050	1055.9240	796.9430	633.5544	527.9620
45	2025	1590.4350	55.2233	2761.1050	2209.9330	1656.0990	1380.5825	1104.4060	828.3475	662.6796	552.2330
46	2116	1661.9064	57.7050	2885.2500	2308.2000	1731.1500	1442.6250	1154.1000	865.3750	692.4600	577.2500
47	2209	1734.9486	60.2412	3012.0000	2409.6400	1807.2360	1506.0300	1204.9240	903.6180	722.8944	602.4120
48	2304	1809.5616	62.8320	3142.0000	2513.3800	1884.9900	1570.8000	1259.6100	942.4800	753.9840	628.3200
49	2401	1885.7545	65.4772	3275.8000	2619.0880	1964.3160	1640.4300	1309.5400	982.1580	785.7264	654.7720
50	2500	1963.5000	68.1770	3408.0000	2727.0000	2044.5100	1704.4250	1363.5400	1022.6550	818.1240	681.7700
51	2601	2042.8254	70.9313	3546.5950	2837.1500	2127.9390	1773.2825	1418.2000	1063.0695	851.1756	709.3130
52	2704	2123.7216	73.7055	3689.2750	2948.2200	2211.1050	1842.6375	1474.1100	1105.5825	884.4660	737.0550
53	2809	2206.1886	76.6037	3830.1850	3064.1300	2298.1100	1915.0925	1532.0740	1149.0550	919.2444	761.0370
54	2916	2290.2254	79.5216	3976.0800	3180.8400	2385.6430	1988.0400	1590.4320	1192.8240	954.2592	795.2160
55	3025	2375.8350	82.4942	4124.7100	3299.7630	2477.8200	2062.3550	1649.8340	1237.4130	989.9304	824.9420
56	3136	2463.0445	85.5021	4275.1050	3420.0340	2565.0630	2137.5525	1710.0420	1282.5315	1026.0242	855.0210
57	3249	2551.7646	88.6028	4430.1400	3544.1120	2653.0840	2215.0700	1772.0560	1329.0420	1063.3336	886.0080
58	3364	2642.0856	91.7991	4589.5050	3669.5640	2752.1750	2293.4775	1834.7820	1376.0875	1100.8692	917.3910
59	3481	2733.9774	94.9297	4746.1050	3797.1880	2847.8920	2373.2425	1890.5940	1423.9455	1139.1504	949.2970
60	3600	2827.4100	98.1750	4908.7500	3927.0000	2945.2500	2454.3750	1963.5000	1472.6250	1178.1000	981.7500
61	3721	2922.4734	101.4747	5073.7350	4058.9880	3044.2875	2530.8750	2029.4900	1522.1205	1217.6924	1014.7470
62	3844	3019.0776	104.8290	5241.4500	4193.1000	3144.8700	2622.7250	2096.5800	1572.4350	1257.6480	1048.3900
63	3969	3117.2526	108.2128	5410.6400	4328.5120	3246.3340	2705.3200	2164.2560	1623.1520	1298.5536	1082.1280
64	4096	3216.9644	111.6665	5583.3250	4466.6600	3349.9950	2791.6125	2233.3300	1674.9975	1339.9980	1116.6650
65	4225	3317.3150	115.2192	5760.9600	4608.7680	3456.5700	2880.4500	2304.3840	1728.2880	1382.6304	1152.1920
66	4356	3421.2024	118.7027	5949.6350	4751.7080	3563.7810	2969.8175	2377.8540	1781.8905	1425.5124	1187.9270
67	4489	3525.6506	122.4187	6120.9350	4896.7480	3672.5610	3060.4675	2449.3740	1835.2805	1469.0244	1249.1870
68	4624	3631.6896	126.1002	6305.2100	5044.0080	3783.0060	3152.5500	2522.0000	1891.5030	1513.2034	1261.0000
69	4761	3739.2894	129.8363	6491.8150	5193.4520	3895.0890	3245.9075	2596.7200	1947.5445	1558.0356	1298.3630
70	4900	3849.4600	133.6271	6681.3550	5345.0840	4008.8130	3340.6775	2672.5420	2004.4065	1603.5252	1336.2710
71	5041	3951.2040	137.4722	6873.6100	5498.8880	4124.1600	3436.8500	2749.4440	2062.0830	1649.6664	1374.7220
72	5184	4054.5141	141.3720	7068.6000	5654.8800	4241.1600	3534.3000	2827.4400	2120.5800	1696.4640	1413.7200
73	5329	4159.3956	145.3202	7265.3100	5813.2480	4359.7860	3633.1550	2905.5240	2179.9390	1743.9144	1453.2620
74	5476	4265.8504	149.3350	7466.7500	5973.4000	4480.0500	3733.3750	2986.7000	2240.0250	1792.0200	1493.3500
75	5625	4373.8750	153.3973	7671.2150	6135.9280	4602.9290	3834.9575	3067.9690	2300.9745	1840.1796	1533.9845
76	5776	4483.4704	157.5162	7879.8100	6300.6480	4725.4360	3937.1050	3150.3240	2367.7430	1890.1944	1575.1620
77	5929	4594.6560	161.6540	8082.7000	6466.1000	4849.6000	4041.1500	3233.0800	2434.8100	1939.8180	1616.5400
78	6084	4707.3736	165.9157	8290.5750	6636.0280	4977.4710	4147.8925	3318.3140	2488.7350	1990.9874	1659.1570
79	6241	4821.6814	170.2972	8503.8600	6807.8830	5105.9160	4254.9300	3403.9440	2552.9580	2042.3664	1701.9720
80	6400	4937.5000	174.5332	8720.6600	6981.3280	5235.9960	4363.3300	3490.6640	2607.9980	2094.3984	1745.3320
81	6561	5054.8094	178.9238	8946.1000	7156.9250	5367.7140	4473.0950	3578.4760	2683.8570	2147.0856	1789.2380
82	6724	5173.6290	183.3690	9180.1500	7334.7000	5501.0700	4584.2250	3667.3800	2750.5350	2204.4283	1833.6900
83	6889	5294.0620	187.8697	9423.2500	7514.7480	5636.0610	4696.7175	3757.3740	2818.0305	2254.4244	1878.6870
84	7056	5416.1224	192.4232	9671.1600	7706.9240	5772.6660	4810.5800	3848.4640	2886.3480	2309.0784	1924.2300
85	7225	5540.8150	197.0317	9921.5850	7891.1268	5910.9510	4925.7925	3940.6340	2955.4755	2364.3804	1970.3170
86	7396	5667.1384	201.6950	10174.7500	8067.8000	6050.8500	5042.3750	4033.9000	3025.4250	2420.3400	2016.9500
87	7569	5794.9920	206.4128	10429.4000	8236.3120	6192.8400	5160.3200	4128.2560	3096.1920	2476.9356	2064.1280
88	7744	5924.1576	211.2122	10685.9000	8407.4880	6335.9500	5279.6300	4223.7540	3167.7780	2531.2224	2111.8770
89	7921	6054.7344	216.0122	10950.6100	8640.4880	6480.3660	5400.3050	4320.2440	3240.1880	2592.1464	2160.1220
90	8100	6186.7400	220.8937	11204.6850	8835.7430	6626.8110	5522.3425	4417.8740	3313.4055	2650.7244	2208.9370
91	8281	6320.3974	225.8297	11458.1450	9035.1380	6774.8910	5645.7425	4516.5940	3387.4450	2709.9554	2258.2970
92	8464	6455.6560	230.8656	11711.5430	9234.6240	6925.9680	5771.6400	4617.3120	3462.4840	2770.3872	2308.6500
93	8649	6592.6240	235.9553	11973.2650	9434.6120	7075.9590	5896.6325	4717.3060	3547.9795	2830.3636	2358.6530
94	8836	6731.2994	240.9560	12244.7300	9638.2400	7228.6800	6023.9000	4819.1200	3614.3400	2891.4720	2409.5600
95	9025	6871.2350	246.1187	12520.9350	9844.7480	7383.5610	6152.9675	4922.3740	3691.7805	2953.4244	2461.3740
96	9216	7012.4544	251.3282	12800.6100	10053.1280	7539.8460	6283.2050	5026.5640	3764.9230	3015.9384	2513.2800
97	9409	7154.8206	256.5912	13082.9500	10263.6480	7697.7360	6414.7800	5131.8240	3848.8860	3079.0944	2565.9120
98	9604	7300.3166	261.9090	13367.4500	10476.3600	7857.5700	6547.7250	5238.6800	3928.7850	3142.9080	2619.3400
99	9801	7447.9054	267.2813	13664.0650	10691.2520	8018.4390	6682.0325	5345.6260	4009.2195	3207.3756	2672.3130
100	10000	7597.5000	272.7082	13963.4100	10908.3280	8181.2460	6817.7050	5454.1640	4090.1230	3272.4984	2727.0810

BLOWING OF GLASS

TABLE III. of Blowing Cylinders, their Area, Capacity, and Quantity of Air Discharged by a Six-Foot Stroke.

Di- am- eter in Inches.	Area in Circles in Sq. In.	Area in Squares in Sq. In.	Capacity of the Cylinder in Cubic Feet.	Air discharged at the Rate of 12 Cylinders per Minute in Cubic Feet.	Air discharged at the Rate of 10 Cylinders per Minute in Cubic Feet.	Air discharged at the Rate of 8 Cylinders per Minute in Cubic Feet.	Air discharged at the Rate of 6 Cylinders per Minute in Cubic Feet.	Air discharged at the Rate of 4 Cylinders per Minute in Cubic Feet.	Air discharged at the Rate of 2 Cylinders per Minute in Cubic Feet.	Air life span at the Rate of 12 Cylinders per Minute in Cubic Feet.	
36	1296	1017.8784	42.4116	2120.5800	1595.4540	1272.3480	1060.2900	848.2320	636.1740	508.9392	424.1160
37	1369	1075.8670	44.8005	2240.0250	1792.0200	1344.0150	1120.0125	896.0100	672.0075	537.6060	448.0050
38	1444	1134.1176	47.2548	2362.7400	1890.1920	1417.6440	1181.3700	945.0960	708.8220	567.0576	472.5480
39	1521	1194.5934	49.7746	2488.7100	1990.9840	1493.2380	1244.3650	995.4920	746.6190	597.2952	497.7460
40	1600	1256.6400	52.3582	2617.9100	2091.3280	1570.7460	1308.9550	1047.1640	785.3730	628.2986	523.5420
41	1681	1320.7574	55.0107	2750.5350	2200.4280	1650.3210	1375.2675	1100.2140	825.1605	660.1284	550.1070
42	1764	1385.4456	57.7251	2886.2550	2309.0040	1731.7530	1443.1275	1154.5020	865.8765	692.7012	574.2510
43	1849	1452.2046	60.5085	3025.4250	2420.3400	1815.2550	1512.7125	1210.1740	907.6275	726.1020	605.6870
44	1936	1520.5344	63.3555	3167.7750	2534.2200	1900.6650	1583.8875	1267.1100	950.3325	760.2660	638.5500
45	2025	1590.4350	66.2680	3313.4000	2650.7200	1988.0490	1656.2000	1325.3600	999.0200	795.1960	662.6820
46	2116	1661.9064	69.2460	3462.3000	2769.8400	2077.3800	1731.1500	1384.4200	1038.6900	830.9520	692.2100
47	2209	1734.9486	72.2895	3614.4750	2891.5800	2168.6850	1807.2375	1445.2900	1084.3425	867.4740	722.6450
48	2304	1809.5616	75.3984	3769.9200	3015.9360	2261.9520	1834.9600	1507.9680	1130.9760	904.7808	753.9840
49	2401	1885.7572	78.5727	3928.6350	3142.9080	2357.1810	1964.3175	1571.4540	1178.5950	942.8724	785.7270
50	2500	1963.5000	81.8124	4090.6200	3272.4960	2454.3720	2045.3100	1636.4980	1227.6860	981.7488	818.2490
51	2601	2042.8254	85.1176	4255.8800	3404.7040	2553.5280	2127.9400	1702.3520	1276.7640	1024.4112	851.1760
52	2704	2123.7216	88.4466	4422.3300	3537.8640	2653.3980	2211.1650	1768.9320	1326.6940	1066.5592	884.4660
53	2809	2206.1886	91.9246	4596.2300	3676.9840	2757.7380	2298.1150	1838.4920	1378.8690	1103.0952	919.4920
54	2916	2290.2264	95.4259	4771.2950	3817.0360	2862.7770	2385.6475	1908.5180	1431.3885	1143.1108	954.2560
55	3025	2375.8350	98.9931	4949.6550	3959.7240	2969.7930	2474.8275	1979.8620	1484.8965	1187.9172	989.9310
56	3136	2463.0144	102.6025	5130.1250	4104.1000	3078.0750	2565.0625	2052.0500	1539.0375	1231.2300	1026.0250
57	3249	2551.7646	106.3234	5316.1700	4252.9360	3189.7020	2668.0850	2126.4680	1594.3510	1275.8604	1063.2340
58	3364	2642.0856	110.0869	5504.3450	4402.7560	3302.6070	2752.1725	2201.3780	1651.3035	1321.0428	1100.6690
59	3481	2733.9774	113.9157	5695.7850	4556.6280	3417.4710	2847.8925	2278.3140	1708.7355	1366.9884	1139.1570
60	3600	2827.4400	117.8100	5890.5000	4712.4000	3534.3000	2945.2500	2356.2000	1767.1500	1413.7200	1178.1000
61	3721	2922.4734	121.7697	6088.4850	4870.7800	3653.0910	3044.2425	2435.3900	1826.5450	1461.2364	1217.6950
62	3844	3019.0776	125.7943	6289.7400	5031.7920	3773.8440	3144.8700	2515.8960	1886.9220	1509.5376	1257.9180
63	3969	3117.2526	129.8544	6492.7200	5194.1640	3895.6320	3246.3600	2592.0820	1947.8160	1558.2528	1296.0410
64	4096	3216.9984	133.9998	6699.9900	5359.9920	4019.9940	3349.9950	2679.9960	2009.9970	1609.9976	1339.9980
65	4225	3318.3150	138.2631	6913.1550	5530.5240	4147.8930	3456.5750	2765.2620	2073.9465	1659.1572	1382.6310
66	4356	3421.2024	142.5501	7127.5050	5702.0040	4276.5030	3563.7525	2851.0020	2138.2515	1710.6012	1425.5010
67	4489	3525.6606	146.9025	7345.1250	5876.1090	4407.0750	3672.5625	2938.0500	2203.5375	1762.8300	1469.0250
68	4624	3631.6806	151.3203	7566.0100	6052.8120	4539.6090	3782.0075	3026.4060	2269.8045	1815.8436	1513.2030
69	4761	3739.2894	155.8036	7790.1800	6232.1440	4674.1080	3895.0900	3116.0720	2337.0540	1869.9360	1558.0360
70	4900	3848.4600	160.3525	8017.6250	6414.1000	4810.5750	4008.8125	3207.0500	2405.2875	1924.2300	1603.5250
71	5041	3959.2014	164.9667	8248.3350	6598.6680	4949.0010	4124.1675	3299.3340	2474.5050	1979.6004	1649.6670
72	5184	4071.5156	169.6464	8482.3200	6785.8560	5089.3920	4241.1600	3392.9280	2544.6960	2035.7568	1696.4640
73	5329	4185.3966	174.3915	8719.5750	6975.6600	5231.7450	4359.7875	3487.8300	2615.8725	2092.6980	1743.9150
74	5476	4300.8504	179.2020	8960.1000	7168.0800	5376.0600	4480.0500	3584.0400	2688.0300	2150.4240	1792.0200
75	5625	4417.8750	184.0780	9203.9000	7363.1200	5522.3400	4601.9500	3681.5600	2761.1700	2208.0360	1840.7800
76	5776	4536.4704	189.0195	9450.9750	7560.7800	5670.5850	4725.4875	3780.3900	2835.2925	2268.2340	1890.1050
77	5929	4656.6366	193.9848	9699.2400	7759.3920	5819.5440	4849.6200	3879.6960	2909.7720	2327.8176	1939.8480
78	6084	4778.3736	199.0989	9954.9490	7963.9560	5972.9670	4977.4745	3981.9780	2986.4835	2399.1868	1990.9890
79	6241	4901.6814	204.2367	10211.8350	8169.4680	6127.1010	5105.9175	4084.7340	3063.5505	2450.8404	2047.3670
80	6400	5026.5600	209.4399	10471.9950	8377.5960	6283.1970	5235.9975	4188.7980	3141.5985	2513.2788	2094.3990
81	6561	5153.0094	214.7086	10735.4300	8583.3440	6441.2580	5367.7150	4294.1720	3220.1290	2576.5032	2147.0860
82	6724	5281.0296	220.0428	11002.1400	8801.7120	6601.2840	5501.0700	4400.3560	3300.6420	2640.5136	2200.1780
83	6889	5410.6206	225.4425	11272.1250	9017.7000	6763.2750	5636.0625	4508.8500	3381.6375	2705.3100	2254.4250
84	7056	5541.7824	230.9079	11545.3950	9236.3160	6927.2370	5772.6975	4618.1580	3463.6185	2770.8948	2309.9790
85	7225	5674.5150	236.4381	11821.9050	9457.5240	7093.1430	5910.9525	4728.7620	3546.5715	2837.2572	2364.8810
86	7396	5808.8184	242.0340	12101.7000	9681.3500	7261.0200	6050.8500	4840.1800	3630.5100	2904.4080	2420.9900
87	7569	5944.6926	247.6954	12384.7700	9907.8160	7430.8620	6192.3850	4953.9080	3715.4310	2972.3448	2476.9540
88	7744	6082.1376	253.4223	12671.1150	10136.8920	7602.6690	6335.5575	5068.4460	3801.3345	3041.0676	2534.2230
89	7921	6221.1534	259.2147	12960.7350	10368.5880	7776.4410	6480.3675	5184.2940	3883.2205	3110.5764	2592.1470
90	8100	6361.7420	265.0725	13253.6250	10602.9000	7952.1750	6626.8125	5301.4500	3976.0875	3180.8700	2650.7250
91	8281	6503.9974	270.9957	13549.7850	10839.8280	8129.8710	6774.8925	5419.9140	4064.9350	3251.9484	2709.9570
92	8464	6647.8256	276.9843	13849.2150	11079.3720	8309.5290	6924.6075	5539.6860	4154.7645	3323.8116	2769.8430
93	8649	6792.9246	283.0384	14151.9200	11321.5360	8491.1520	7075.9600	5660.7680	4245.5760	3376.4608	2830.3440
94	8836	6939.7944	289.1580	14457.9000	11566.3200	8674.7400	7228.4500	5783.1600	4337.3700	3469.8960	2891.5800
95	9025	7088.2350	295.3431	14767.1550	11818.7240	8860.2930	7383.5750	5906.8620	4430.1465	3544.1172	2953.4310
96	9216	7238.2464	301.5939	15079.6950	12063.7560	9047.8170	7535.8475	6031.8780	4523.9085	3619.1268	3015.9390
97	9409	7389.2816	307.9095	15395.4750	12316.3800	9237.2850	7697.7375	6158.1900	4618.6475	3694.9140	3079.0950
98	9604	7541.8286	314.3038	15715.0400	12572.0320	9429.0240	7857.5200	6286.0160	4714.5120	3771.6096	3143.0080
99	9801	7697.7054	320.7376	16036.8800	12829.5040	9622.1280	8018.4400	6414.7520	4811.0640	3848.8512	3207.3760
100	10000	7854.0000	327.2499	16362.4950	13089.9960	9817.4970	8181.2475	6544.9980	4908.7485	3926.9988	3272.4990

BLOWING OF GLASS

TABLE IV. of Blowing Cylinders, their Area, Capacity, and Quantity of Air discharged by a Seven-Foot Stroke.

Di- am- eter of the Cylinder in Inches.	Area in Circular Inches.	Area in Square Inches.	Capacity of the Stroke in Cubic Feet.	Air discharged at the Rate of 50 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 40 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 30 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 25 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 20 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 15 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 12 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 10 Cylinders per Minute in Cubical Feet.
36	1206	1017.8784	49.4702	2473.5100	1978.8080	1484.1060	1236.7550	989.4040	742.9530	593.0424	494.7020
37	1369	1075.8670	52.2672	2613.3600	2090.6880	1568.0160	1306.6800	1045.3440	784.0080	627.2064	522.6720
38	1444	1134.1176	55.1306	2756.5300	2205.2240	1653.9180	1378.2650	1102.0120	826.9590	661.5672	551.3060
39	1521	1194.5934	58.0705	2903.5250	2322.8200	1742.1150	1451.7625	1161.4100	871.0575	696.8460	580.7050
40	1600	1256.6400	61.0845	3054.2250	2443.3800	1832.5350	1527.1125	1221.6900	916.2675	733.0140	610.8450
41	1681	1320.2574	64.1791	3208.9550	2567.1640	1925.3730	1604.4775	1283.5820	912.6865	770.1492	641.7910
42	1764	1385.4456	67.3459	3367.2950	2693.8360	2020.3770	1683.6475	1340.9180	1010.1885	808.1508	673.4590
43	1849	1452.2046	70.5932	3529.6000	2823.7280	2117.3300	1764.8300	1411.8640	1058.6650	847.1184	705.9320
44	1936	1520.5344	73.9110	3695.5500	2963.4400	2217.3300	1847.7750	1468.2200	1108.6600	886.9320	734.1100
45	2025	1590.4350	77.3126	3865.6300	3092.5040	2319.3780	1932.8150	1546.2520	1159.6890	927.7512	773.1260
46	2116	1661.9064	80.7870	4039.3500	3231.4800	2423.6100	2019.6750	1615.7400	1211.8050	969.4440	807.8700
47	2209	1734.9486	84.3377	4216.8850	3373.5080	2530.1310	2108.4425	1686.7540	1265.0650	1012.0524	843.3750
48	2304	1809.5616	87.9648	4398.1400	3518.5920	2635.9440	2199.1200	1759.2960	1319.4720	1055.5776	879.6480
49	2401	1885.7545	91.6681	4584.4050	3666.7240	2745.0430	2292.2050	1833.3620	1375.6215	1100.0172	916.6810
50	2500	1963.5000	95.4478	4772.3900	3817.9120	2863.4340	2386.1950	1908.9560	1431.2120	1145.3736	954.4780
51	2601	2042.8254	99.3038	4965.4400	3972.1520	2979.1140	2482.7200	1986.0760	1489.5570	1191.6456	993.0380
52	2704	2123.7216	103.1877	5159.3850	4127.5080	3095.6310	2579.6925	2063.7540	1547.8150	1238.2524	1031.8770
53	2809	2206.1886	107.2453	5362.2650	4289.8120	3217.3590	2681.1325	2144.9060	1608.1795	1286.9436	1072.4530
54	2916	2290.2264	111.3302	5566.5100	4461.3200	3343.9060	2783.2550	2226.6040	1669.9530	1335.9624	1113.3020
55	3025	2375.8350	115.4919	5774.5950	4641.6760	3464.7570	2878.2975	2309.8380	1732.3785	1385.9028	1154.9140
56	3136	2463.0144	119.7029	5988.1450	4788.1160	3591.0870	2992.5725	2394.0580	1795.5435	1436.4348	1197.0290
57	3249	2551.7646	124.0439	6202.1950	4961.7560	3721.3170	3101.0975	2480.8780	1860.6585	1488.5268	1240.4390
58	3364	2642.0856	128.4347	6421.7350	5137.3880	3853.0410	3210.8675	2568.6940	1926.5205	1542.2164	1284.3470
59	3481	2733.9774	132.9016	6645.0800	5316.0640	3987.0480	3322.5400	2658.0320	1993.5240	1594.8192	1329.0160
60	3600	2827.4400	137.4450	6872.2500	5497.8000	4123.3500	3436.1250	2748.4000	2061.6750	1649.3400	1374.2000
61	3721	2922.4734	142.0646	7103.2300	5682.5840	4261.9380	3551.6150	2841.2920	2130.9690	1704.7752	1420.6460
62	3844	3019.0776	146.7606	7338.0300	5870.4240	4402.8180	3669.0150	2935.2120	2201.4090	1761.1272	1467.6060
63	3969	3117.2526	151.4968	7574.8400	6059.8720	4544.9040	3787.4200	3029.9360	2272.4520	1817.9616	1514.9680
64	4096	3216.9984	156.3331	7816.6550	6253.3240	4689.9930	3908.3275	3126.6620	2344.9965	1875.9972	1563.3310
65	4225	3318.3150	161.2664	8018.3200	6466.0560	4846.9920	4054.1600	3243.3280	2424.4260	1945.9968	1612.6640
66	4356	3421.2024	166.3084	8185.4400	6652.3360	4989.2540	4157.7200	3326.1630	2494.6260	1995.7008	1663.0815
67	4489	3525.6606	171.3862	8369.3100	6855.4480	5141.5860	4284.6500	3427.7240	2570.7930	2056.6344	1713.8620
68	4624	3631.6866	176.5403	8572.0150	7061.6120	5296.2090	4413.5075	3530.8060	2648.1045	2118.4836	1765.4030
69	4761	3739.2894	181.7708	9088.5400	7270.8320	5453.1240	4544.2700	3635.4160	2726.5020	2181.2406	1817.7080
70	4900	3848.4600	187.0779	9353.8950	7483.1160	5612.3370	4676.9475	3741.5580	2806.1685	2244.9348	1870.7790
71	5041	3959.2014	192.4611	9623.0550	7698.4440	5773.8330	4811.5275	3849.2220	2886.9165	2309.5332	1929.6110
72	5184	4071.5136	197.9210	9896.0500	7916.8400	5937.6300	4948.0250	3958.4200	2968.8150	2375.0520	1979.2100
73	5329	4185.3966	203.4567	10172.8350	8138.2680	6103.7010	5086.4175	4069.1340	3051.8505	2441.4804	2034.5670
74	5476	4300.5504	209.0690	10453.4500	8362.7600	6272.0700	5226.7250	4181.3800	3136.0350	2508.8280	2090.1900
75	5625	4417.8750	214.7576	10737.8800	8590.3040	6442.7280	5368.9400	4295.1520	3221.3640	2577.0912	2147.5760
76	5776	4536.4704	220.5227	11026.1350	8820.9080	6615.6810	5513.0675	4410.4540	3307.8405	2646.2724	2205.2270
77	5929	4656.6366	226.3156	11315.7800	9052.6240	6789.4680	5657.8900	4526.3120	3394.7340	2715.7872	2263.1560
78	6084	4778.3736	232.2820	11614.1000	9291.2800	6968.4600	5807.0500	4645.6400	3484.2300	2787.8840	2322.8200
79	6241	4901.6814	238.3093	11915.4650	9532.3720	7149.2790	5957.7325	4766.1860	3574.6395	2859.7116	2383.0930
80	6400	5026.5600	244.3465	12217.3250	9773.8600	7330.3950	6108.6625	4886.9300	3665.1975	2932.1580	2443.4650
81	6561	5153.0094	250.4933	12528.16650	10019.7320	7514.7990	6262.3325	5009.8660	3757.3995	3005.9196	2504.9330
82	6724	5281.0296	256.7166	12835.8300	10268.6640	7701.4980	6417.9150	5134.3320	3850.7490	3080.5992	2567.1660
83	6889	5410.6206	263.0162	13150.8100	10520.6480	7890.4860	6575.4050	5260.3240	3945.2430	3156.1944	2630.1620
84	7056	5541.7824	269.3925	13469.6250	10775.7000	8081.7750	6734.8125	5387.8500	4040.8875	3230.7100	2693.9250
85	7225	5674.5150	275.8444	13792.2200	11033.7760	8275.3320	6896.1100	5516.8880	4137.6665	3310.1328	2758.4440
86	7396	5808.8184	282.3730	14118.6500	11294.9200	8471.1900	7059.3250	5647.4600	4235.5950	3388.4760	2823.7300
87	7569	5944.6926	288.9779	14448.8950	11559.1160	8669.3370	7224.4475	5779.5580	4334.6685	3467.7338	2889.7790
88	7744	6082.1576	295.6593	14782.0650	11826.3720	8869.7790	7391.4825	5913.1860	4434.8895	3547.9116	2956.5930
89	7921	6221.1534	302.4171	15120.8550	12096.6840	9072.5130	7560.4275	6048.3420	4536.2565	3629.0052	3024.1720
90	8100	6361.7400	309.2512	15462.5600	12370.0480	9277.5360	7731.2800	6185.0240	4638.7638	3711.0144	3092.5120
91	8281	6503.8974	316.1616	15808.0800	12646.4640	9484.8480	7904.0400	6323.2320	4742.4240	3793.9392	3161.6160
92	8464	6647.6256	323.1483	16157.4150	12925.9320	9694.4490	8078.7075	6462.9660	4847.2245	3877.7796	3231.4830
93	8649	6792.9246	330.2114	16510.5700	13208.4560	9906.3420	8255.2850	6604.2280	4953.1710	3962.5368	3302.1140
94	8836	6939.7944	337.3510	16867.5500	13494.0400	10120.5300	8433.7750	6747.0200	5062.2050	4048.2120	3373.5120
95	9025	7088.2350	344.5669	17228.3450	13784.6760	10337.0070	8614.1725	6891.3380	5168.5735	4134.8028	3445.6690
96	9216	7238.2464	351.8595	17592.9750	14074.3800	10555.7850	8796.4875	7037.1900	5277.8925	4222.3140	3518.5950
97	9409	7389.8286	359.3044	17969.7200	14375.7700	10781.8320	8984.8600	7187.8880	5390.9160	4312.7328	3593.9440
98	9604	7542.9816	366.6842	18334.2100	14667.3600	11000.5260	9167.1050	7333.0840	5552.2630	4400.2104	3666.8420
99	9801	7697.7054	374.1938	18709.6000	14967.7500	11258.8140	9354.3450	7483.8760	5612.9970	4490.3256	3741.9380
100	10000	7854.0000	381.7915	19089.5750	15271.6600	11453.7450	9544.7875	7635.8100	5726.8725	4581.4980	3817.9150

BLOWING OF GLASS

TABLE V. of the Powers of Steam Engines working at the Rate of 9lbs. Avoirdupoise, upon every Circular Inch, or 11.4 lbs. upon every Square Inch of the Steam Piston applicable to Blowing Machinery; and the Areas and Diameters of Blowing Cylinders requisite to raise Air of various Densities from 1½ lbs. to 4lbs. upon each Circular Inch, or from 1.90lb. to 5.092lbs. Avoirdupoise, upon each Square Inch of the Air receiver.

[illegible]

BLOWING OF GLASS

TABLE I. of the Powers of Steam Engines working at the Rate of 5 lbs. Avoirdupois upon every Circular Inch, or 6.3656 lb. upon every Square Inch of the Steam Piston applicable to Blowing Machinery; and the Areas and Diameters of Blowing Cylinders requisite to raise Air of various Densities from $1\frac{1}{2}$ lb. to 4 lbs. upon each Circular Inch, or from 1.90 lb. to 5.092 lbs. Avoirdupois upon each Square Inch of the Air Receiver.

Diameter of Steam Cylinder.	Area of Lattice.	Power of the Engine in Horse- Power.	Blind 1 lb. per Circular Inch, or 1.00 lb. per Square Inch.		Blind 1 1/2 lb. per Circular Inch, or 1.25 lb. per Square Inch.		Blind 2 lb. per Circular Inch, or 2.00 lb. per Square Inch.		Blind 2 1/2 lb. per Circular Inch, or 2.50 lb. per Square Inch.		Blind 3 lb. per Circular Inch, or 3.00 lb. per Square Inch.		Blind 3 1/2 lb. per Circular Inch, or 3.50 lb. per Square Inch.		Blind 4 lb. per Circular Inch, or 4.00 lb. per Square Inch.		Blind 4 1/2 lb. per Circular Inch, or 4.50 lb. per Square Inch.		Blind 5 lb. per Circular Inch, or 5.00 lb. per Square Inch.					
			Area of blowing Cylinder.	Diam. of Ditto.	Area of blowing Cylinder.	Diam. of Ditto.	Area of blowing Cylinder.	Diam. of Ditto.	Area of blowing Cylinder.	Diam. of Ditto.	Area of blowing Cylinder.	Diam. of Ditto.	Area of blowing Cylinder.	Diam. of Ditto.	Area of blowing Cylinder.	Diam. of Ditto.	Area of blowing Cylinder.	Diam. of Ditto.	Area of blowing Cylinder.	Diam. of Ditto.				
20	400	2000	1333	36 1/4	1142	34	1000	32	888	29 1/2	800	28 1/2	727	27	666	26	615	24 3/4	571	24	533	23	500	22 1/2
21	441	2205	1470	38 1/4	1260	35 1/2	1102	33 1/2	980	31 1/2	882	29 1/2	801	28 1/2	735	27 1/2	678	26	630	25	588	24	551	23 1/2
22	484	2420	1613	40	1383	37 1/2	1210	35	1075	33	963	31	880	29 1/2	806	28 1/2	744	27 1/2	690	26 1/2	645	25 1/2	605	24 1/2
23	529	2645	1763	42	1511	39	1322	36 1/2	1175	34 1/2	1058	32 1/2	961	31	881	29 1/2	813	28 1/2	755	27 1/2	705	26 1/2	661	25 1/2
24	576	2880	1920	44	1645	40 1/2	1440	38	1280	35 1/2	1152	33 1/2	1047	32 1/2	960	31	886	29 1/2	822	28 1/2	768	27 1/2	720	27
25	625	3125	2083	45 1/2	1785	42 1/2	1562	39 1/2	1388	37 1/2	1250	35 1/2	1130	33 1/2	1041	32 1/2	961	31	892	29 1/2	833	29	781	28
26	676	3380	2253	47 1/2	1931	44	1690	41	1502	38 1/2	1352	36 1/2	1229	35	1126	33 1/2	1040	32 1/2	965	31	901	30	845	29
27	729	3645	2430	49 1/2	2082	45 1/2	1822	42 1/2	1620	40 1/2	1458	38	1325	36 1/2	1215	33 1/2	1121	33 1/2	1041	32 1/2	972	31	911	30 1/2
28	784	3920	2613	51	2240	47 1/2	1960	44	1742	41 1/2	1568	39 1/2	1425	37 1/2	1306	36	1206	34 1/2	1120	33 1/2	1045	32 1/2	980	31 1/2
29	841	4205	2803	53	2402	49	2102	45 1/2	1868	43 1/2	1682	41	1529	39	1401	37 1/2	1293	36	1201	34 1/2	1121	33 1/2	1051	32 1/2
30	900	4500	3000	54 1/2	2571	50 1/2	2250	47 1/2	2000	44 1/2	1800	42 1/2	1636	40 1/2	1500	38 1/2	1384	37 1/2	1285	36	1200	34 1/2	1125	33 1/2
31	961	4805	3203	56 1/2	2745	52 1/2	2402	49	2135	46 1/2	1922	44	1747	41 1/2	1601	40	1478	38 1/2	1371	37 1/2	1281	36	1201	34 1/2
32	1024	5120	3413	58 1/2	2925	54	2560	50 1/2	2275	47 1/2	2048	45 1/2	1861	43	1706	41 1/2	1575	39 1/2	1462	38 1/2	1365	37	1280	35 1/2
33	1089	5445	3630	60 1/2	3111	55 1/2	2722	52	2420	49 1/2	2178	46 1/2	1980	44 1/2	1815	42 1/2	1675	41	1554	39 1/2	1452	38	1361	37
34	1156	5780	3853	62	3302	57 1/2	2890	53 1/2	2568	50 1/2	2312	48 1/2	2101	46	1926	43 1/2	1770	42 1/2	1651	40 1/2	1541	39 1/2	1445	38
35	1225	6125	4083	64	3500	59 1/2	3062	55 1/2	2722	52 1/2	2450	49 1/2	2227	47 1/2	2041	45	1884	43 1/2	1748	41 1/2	1633	40 1/2	1531	39 1/2
36	1296	6480	4320	66	3702	61	3240	57	2880	53 1/2	2592	50 1/2	2356	48 1/2	2160	46 1/2	1993	44 1/2	1851	43	1728	41 1/2	1620	40 1/2
37	1369	6845	4563	67 1/2	3911	62 1/2	3422	58 1/2	3042	55 1/2	2738	52 1/2	2489	49 1/2	2281	47 1/2	2106	46	1954	44 1/2	1825	42 1/2	1711	41 1/2
38	1444	7220	4800	69 1/2	4125	64 1/2	3610	60	3208	56 1/2	2888	53 1/2	2625	51 1/2	2406	49	2221	47 1/2	2062	45 1/2	1925	44	1805	42 1/2
39	1521	7605	5070	71	4345	66	3802	61 1/2	3380	58	3042	55	2765	52 1/2	2535	50 1/2	2338	48 1/2	2172	46 1/2	2028	45	1901	44 1/2
40	1600	8000	5333	73	4571	67 1/2	4000	63 1/2	3555	59 1/2	3200	56 1/2	2909	54	2666	51 1/2	2461	49 1/2	2285	47 1/2	2033	46 1/2	2000	44 1/2
41	1681	8405	5603	75	4802	69 1/2	4202	64 1/2	3735	61	3362	58	3056	55 1/2	2801	53	2586	51	2400	49	2241	47 1/2	2101	45 1/2
42	1764	8820	5880	76 1/2	5040	71	4410	66 1/2	3920	62 1/2	3528	59 1/2	3207	56 1/2	2940	54 1/2	2713	52 1/2	2520	50 1/2	2352	48 1/2	2205	47
43	1849	9245	6230	79	5340	72 1/2	4622	68	4108	64	3698	60 1/2	3361	58	3081	55 1/2	2844	53 1/2	2656	51 1/2	2465	49 1/2	2311	48
44	1936	9680	6453	80 1/2	5531	74 1/2	4840	69 1/2	4302	65 1/2	3872	62 1/2	3520	59 1/2	3226	57 1/2	2978	54 1/2	2765	52 1/2	2581	50 1/2	2420	49 1/2
45	2025	10125	6750	82	5784	76	5062	71	4500	67	4050	63 1/2	3681	60 1/2	3375	58	3115	56	2891	53 1/2	2700	52	2531	50 1/2
46	2116	10580	7053	84	6004	77 1/2	5290	72 1/2	4704	68 1/2	4232	65	3847	62	3526	59 1/2	3255	57	3022	55	2821	53	2645	51 1/2
47	2209	11045	7363	85 1/2	6311	79 1/2	5522	74 1/2	4891	70	4418	66 1/2	4016	63 1/2	3681	60 1/2	3398	58 1/2	3155	56 1/2	2945	54 1/2	2761	52 1/2
48	2304	11520	7680	87 1/2	6582	81	5760	75 1/2	5120	71 1/2	4608	67 1/2	4189	64 1/2	3840	62	3544	59 1/2	3291	57 1/2	3072	55 1/2	2880	53 1/2
49	2401	12005	8003	89 1/2	6857	82 1/2	6002	77 1/2	5335	73	4802	69 1/2	4365	66	4001	63 1/2	3693	60 1/2	3428	58 1/2	3201	56 1/2	3001	54 1/2
50	2500	12500	8333	91 1/2	7142	84 1/2	6250	79	5555	74 1/2	5000	71 1/2	4545	67 1/2	4166	64 1/2	3846	62	3571	59 1/2	3333	58	3125	56
51	2601	13005	8666	93	7431	86 1/2	6502	80 1/2	5780	76	5202	72 1/2	4729	68 1/2	4335	66	4001	63 1/2	3714	61	3468	59	3251	57
52	2704	13520	9013	95	7725	88	6760	82 1/2	6008	77 1/2	5408	73 1/2	4916	70	4506	67 1/2	4160	64 1/2	3862	62 1/2	3605	60	3380	58
53	2809	14045	9363	96 1/2	8025	89 1/2	7022	83 1/2	6242	79	5618	75	5107	71 1/2	4681	68 1/2	4321	65 1/2	4012	63 1/2	3745	61 1/2	3511	59 1/2
54	2916	14580	9720	98 1/2	8831	91 1/2	7290	85 1/2	6480	80 1/2	5832	76 1/2	5301	72 1/2	4860	69 1/2	4486	67 1/2	4165	64 1/2	3888	62 1/2	3645	60 1/2
55	3025	15125	10083	100 1/2	8642	93	7562	87	6722	82	6050	78 1/2	5500	74 1/2	5041	71	4653	68 1/2	4321	65 1/2	4033	63 1/2	3781	61 1/2
56	3136	15680	10453	102 1/2	8960	94 1/2	7840	88 1/2	6968	83 1/2	6272	79 1/2	5701	75 1/2	5226	72 1/2	4824	69 1/2	4480	67 1/2	4181	64 1/2	3920	62 1/2
57	3249	16245	10830	104	9282	96 1/2	8122	90	7220	85	6498	80 1/2	5907	76 1/2	5415	73 1/2	4996	70 1/2	4640	68 1/2	4332	65 1/2	4061	63 1/2
58	3364	16820	11213	106	9611	98	8410	91 1/2	7475	86 1/2	6728	82	6112	78 1/2	5606	75	5175	72	4805	69 1/2	4481	67	4205	64 1/2
59	3481	17405	11603	107 1/2	9945	99 1/2	8702	93 1/2	7735	88	6962	83 1/2	6329	79 1/2	5801	76 1/2	5355	73 1/2	4971	70 1/2	4641	68	4351	66
60	3600	18000	12000	109 1/2	10285	101 1/2	9000	95	8000	89 1/2	7200	84 1/2	6545	81	6000	77 1/2	5538	74 1/2	5142	71 1/2	4800	69 1/2	4500	67
61	3721	18605	12403	111 1/2	10628	103 1/2	9302	96 1/2	8268	91	7460	86 1/2	6765	82 1/2	6201	78 1/2	5724	75 1/2	5315	73	4961	70 1/2	4650	68 1/2
62	3844	19220	12813	112 1/2	10982	104 1/2	9610	98	8542	92 1/2	7688	87 1/2	6989	83 1/2	6406	80	5913	77	5491	74	5125	71 1/2	4805	69 1/2
63	3969	19845	13230	115	11340	106 1/2	9922	99 1/2	8820	94	7938	89	7216	85	6615	81 1/2	6106	78 1/2	5697	75 1/2	5292	72 1/2	4961	70 1/2
64	4096	20480	13653	117	11702	108 1/2	10240	101 1/2	9102	95 1/2	8192	90 1/2	7447	86 1/2	6826	82 1/2	6301	79 1/2	5851	76 1/2	5461	74	5120	71 1/2
65	4225	21125	14083	118 1/2	12071	110	10562	102 1/2	9388	97	8482	91 1/2	7681	87 1/2	7041	84	6500	80 1/2	6035	77 1/2	5633	75	5281	72 1/2
66	4356	21780	14520	120 1/2	12445	111 1/2	10890	104 1/2	9680	98 1/2	8712	93 1/2	7920	89	7260	85 1/2	6701	81 1/2	6222	79	5808	76 1/2	5445	73 1/2
67	4489	22445	14963	122 1/2	12825	113 1/2	11222	106	9975	100	8978	94 1/2	8161	90 1/2	7481	86 1/2	6906	83 1/2	6412	80 1/2	5985	77 1/2	5611	75
68	4624	23120	15413	124 1/2	13211	115	11560	107 1/2	10275	101 1/2	9248	96	8407	91 1/2	7706	87 1/2	7113	84 1/2	6605	81 1/2	6165	78 1/2	5780	76
69	4761	23805	15870	126	13602	116 1/2	11902	109	10580	103	9522	97 1/2	8656	93	7935	89								

BLOWING OF GLASS

TABLE II. of the Powers of Steam Engines working at the Rate of 6 lbs. Avoirdupoise upon every Circular Inch, or 7.639 lb. upon every Square Inch of the Steam Piston applicable to Blowing Machinery; and the Areas and Diameters of Blowing Cylinders requisite to raise Air of various Densities from 1½ lb. to 4 lbs. upon each Circular Inch, or from 1.50 lb. to 5.092 lbs. Avoirdupoise upon each Square Inch of the Air Receiver.

Diameter of Steam Cylind.	Area of Ditch.	Power of the Engine in H.P.	Blow 1½ lb. per Circular Inch, or 1.50 lb. per Square Inch.		Blow 2 lb. per Circular Inch, or 2.00 lb. per Square Inch.		Blow 2½ lb. per Circular Inch, or 2.50 lb. per Square Inch.		Blow 3 lb. per Circular Inch, or 3.00 lb. per Square Inch.		Blow 3½ lb. per Circular Inch, or 3.50 lb. per Square Inch.		Blow 4 lb. per Circular Inch, or 4.00 lb. per Square Inch.		Blow 4½ lb. per Circular Inch, or 4.50 lb. per Square Inch.		Blow 5 lb. per Circular Inch, or 5.00 lb. per Square Inch.		Blow 5½ lb. per Circular Inch, or 5.50 lb. per Square Inch.		Blow 6 lb. per Circular Inch, or 6.00 lb. per Square Inch.	
			Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.	Area of Blowing Cylind.	Diam. of Ditch.
20	400	2400	1600	40	1371	37	1200	34½	1066	32½	960	31	872	29½	800	28½	788	27½	685	26½	640	25½
21	441	2646	176	42	1512	38½	1323	36½	1176	34½	1058	32½	962	31	882	29½	814	28½	756	27½	705	26½
22	484	2904	1936	44	1659	40½	1452	38	1290	36	1161	34	1056	32½	968	31	863	30	820	28½	774	27½
23	529	3174	2116	46	1813	42½	1587	39½	1410	37½	1269	35½	1154	34	1058	32½	976	31½	900	30	846	29
24	576	3456	2304	48	1974	44½	1728	41½	1536	39	1382	37	1256	35½	1152	34	1063	32½	987	31½	921	30½
25	625	3750	2500	50	2142	46½	1875	43½	1666	40½	1500	38½	1363	37	1250	35½	1153	34	1071	32½	1000	31½
26	676	4056	2704	52	2317	48	2028	45	1802	42½	1622	40	1475	38½	1352	37	1248	35½	1159	34	1081	32½
27	729	4374	2916	54	2499	50	2187	46½	1944	44	1749	41½	1590	40	1458	38½	1345	36½	1249	35½	1166	34
28	784	4704	3136	56	2688	51½	2352	48½	2090	45½	1880	43½	1710	41½	1568	39½	1447	38	1344	36½	1254	35½
29	841	5046	3364	58	2883	53½	2523	50½	2242	47	2018	45	1834	43	1682	41	1552	39½	1441	38	1345	36½
30	900	5400	3600	60	3085	55½	2700	52	2400	49	2160	46½	1963	44½	1800	42½	1661	40½	1542	39½	1440	37½
31	961	5766	3844	62	3289	57½	2883	53½	2562	50½	2306	48	2096	46	1922	44	1774	42	1645	40½	1537	39
32	1024	6144	4096	64	3510	59	3072	55½	2730	52½	2457	49½	2234	47½	2048	45½	1819	43½	1755	41½	1638	40½
33	1089	6534	4356	66	3733	61	3267	57½	2904	54	2613	51	2376	49	2178	46½	2010	45	1866	43½	1742	41½
34	1156	6936	4624	68	3963	63	3468	59½	3082	55½	2774	52½	2522	50½	2312	48	2134	46½	1981	44½	1849	43
35	1225	7350	4900	70	4200	65	3675	60½	3266	57½	2940	54	2672	51½	2450	49½	2261	47½	2100	45½	1966	44½
36	1296	7776	5184	72	4443	66½	3888	62½	3456	59	3110	55½	2827	53½	2592	51	2392	49	2221	47	2044	44½
37	1369	8214	5476	74	4693	68½	4107	64	3650	60½	3285	57	2986	54½	2738	52½	2527	50½	2346	48½	2190	46½
38	1444	8664	5776	76	4950	70½	4332	65½	3850	62	3465	58½	3150	56	2888	53½	2662	51½	2475	49½	2310	48
39	1521	9126	6084	78	5214	72½	4563	67½	4056	63½	3650	60½	3314	57½	3042	55	2808	53	2607	51½	2433	49½
40	1600	9600	6400	80	5485	74	4800	69½	4266	65½	3840	62	3490	59	3200	56½	2953	54½	2742	52½	2560	50½
41	1681	10086	6724	82	5763	76	5043	71	4482	67	4034	63½	3667	60½	3362	58	3103	55½	2881	53½	2689	51½
42	1764	10584	7056	84	6048	78½	5292	72½	4704	68½	4233	65	3848	62	3528	59½	3256	57	3024	55	2822	53
43	1849	11094	7396	86	6339	79½	5547	74½	4961	70½	4485	66½	4034	62½	3698	60½	3413	58½	3169	56½	2958	54½
44	1936	11616	7744	88	6637	81½	5808	76½	5162	72	4646	68	4224	64	3872	62	3574	60	3318	57½	3097	55½
45	2025	12150	8100	90	6942	83½	6075	78	5400	73½	4860	69½	4418	66½	4050	63½	3738	61½	3471	59	3240	56½
46	2116	12696	8464	92	7254	85	6348	79½	5642	75	5078	71½	4616	68	4232	65	3906	62½	3627	60½	3385	58
47	2209	13254	8836	94	7573	87	6627	81½	5890	76½	5301	73	4819	69½	4418	66½	4076	64	3786	61½	3534	59½
48	2304	13824	9216	96	7899	88½	6912	83½	6144	78½	5529	74½	5026	71	4608	68	4253	66½	3949	62½	3686	60½
49	2401	14400	9604	98	8232	90½	7203	84½	6402	80	5762	76	5236	72½	4802	69½	4432	66½	4116	64	3841	61½
50	2500	15000	10000	100	8571	92½	7500	86½	6666	81½	6000	77½	5454	74	5000	70½	4613	68	4285	65½	4000	63
51	2601	15606	10404	102	8917	94½	7803	88½	6936	83½	6242	79	5675	75½	5202	72	4801	69½	4456	66½	4161	64½
52	2704	16224	10816	104	9270	96½	8112	90	7210	85	6489	80½	5899	77	5408	73½	4992	70½	4635	67½	4326	65½
53	2809	16854	11236	106	9630	98½	8427	91½	7490	86½	6741	82	6125	78½	5618	75	5185	72	4815	69½	4494	67
54	2916	17496	11664	108	9997	100	8748	93½	7776	88	6996	83½	6362	79½	5832	76½	5383	73½	4998	70½	4665	68½
55	3025	18150	12100	110	10371	101½	9075	95½	8066	89½	7260	85½	6600	81½	6050	77½	5584	74½	5185	72	4840	69½
56	3136	18816	12544	112	10752	103½	9408	97½	8362	91½	7526	86½	6842	82½	6272	79½	5789	76	5378	73½	5017	70½
57	3249	19494	12996	114	11139	105½	9747	99½	8664	93	7797	88½	7088	84	6428	80½	5998	77½	5569	74½	5198	72
58	3364	20184	13456	116	11533	107½	10092	100½	8970	94½	8073	89½	7339	85½	6728	82	6210	78½	5765	75½	5382	73½
59	3481	20886	13924	118	11935	109½	10443	102½	9280	96½	8354	91½	7594	87	6962	83½	6426	80	5967	77½	5560	74½
60	3600	21600	14400	120	12342	111	10800	104	9600	98	8640	93	7854	88½	7200	85½	6646	81½	6171	78½	5760	75½
61	3721	22326	14884	122	12754	113	11163	105½	9922	99½	8930	94½	8118	90	7442	86½	6860	83	6378	79½	5933	77
62	3844	23064	15376	124	13179	114½	11532	107½	10250	101½	9215	96	8386	91½	7688	87½	7096	84½	6589	81	6150	78½
63	3969	23814	15875	126	13608	116½	11907	109½	10584	103	9525	97½	8659	93	7938	89	7327	85½	6804	82½	6350	79½
64	4096	24576	16384	128	14043	118½	12288	110½	10922	104½	9830	99	8936	94½	8192	90½	7561	87	7021	83½	6553	80½
65	4225	25350	16900	130	14485	120½	12675	112½	11266	106½	10140	100½	9218	96	8450	92	7800	88½	7242	84½	6766	82
66	4356	26136	17424	132	14934	122½	13068	114½	11610	107½	10454	102½	9504	97½	8712	93	8041	89½	7467	86½	6960	83½
67	4489	26934	17956	134	15390	124	13467	116	11970	109½	10773	103½	9794	99	8978	94½	8287	91	7695	87½	7182	84½
68	4624	27744	18496	136	15853	126	13872	117½	12230	111	11097	105½	10088	100½	9248	96½	8536	92½	7924	89	7398	85½
69	4761	28566	19044	138	16323	127½	14283	119½	12693	112½	11426	107	10387	102	9522	97½	8789	93½	8161	90½	7617	87½
70	4900	29400	19600	140	16800	129½	14700	121½	13066	114½	11760	108½	10690	103½	9800	99½	9046	95	8400	91½	7840	88½

BLOWING OF GLASS

TABLE III. of the Powers of Steam Engines working at the Rate of 7lbs. Avoirdupois upon every Circular Inch, or 8.91lb. upon every Square Inch of the Steam Piston, applicable to Blowing Machinery; and the Areas and Diameters of Blowing Cylinders, requisite to raise Air of various densities from $1\frac{1}{2}$ lb to 4lbs. upon each Circular Inch, or from 1.90lb. to 5.092lbs. Avoirdupois upon each Square Inch of the Air Receiver.

[illegible]

BLOWING OF GLASS

TABLE IV. of the Powers of Steam Engines working at the Rate of 8lbs. Avoirdupois, upon every Circular Inch, or 10.18 lbs. upon every Square Inch of the Steam Piston, applicable to Blowing Machinery; and the Areas and Diameters of Blowing Cylinders requisite to raise Air of various Densities from 1½ lb. to 4 lbs. upon each Circular Inch, or from 1.90 lb. to 5.092 lbs. Avoirdupois upon each Square Inch of the Air Receiver.

No.	Area of Piston in Square Inches	Power of Piston in H.P.	Blow 1 1/2 lb. per Circular Inch, or 1.90 lb. per Square Inch		Blow 2 lb. per Circular Inch, or 2.51 lb. per Square Inch		Blow 3 lb. per Circular Inch, or 3.51 lb. per Square Inch		Blow 4 lb. per Circular Inch, or 4.77 lb. per Square Inch		Blow 5 lb. per Circular Inch, or 5.09 lb. per Square Inch		Blow 6 lb. per Circular Inch, or 6.00 lb. per Square Inch		Blow 7 lb. per Circular Inch, or 7.00 lb. per Square Inch		Blow 8 lb. per Circular Inch, or 8.00 lb. per Square Inch		Blow 9 lb. per Circular Inch, or 9.00 lb. per Square Inch		Blow 10 lb. per Circular Inch, or 10.18 lb. per Square Inch			
			Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto	Area of blowing Cylinder	Diameter of Ditto		
20	400	3200	2133	46 1/2	1828	42 1/2	1600	40	1422	37 1/2	1280	36	1163	34	1066	32 1/2	984	31 1/2	914	30	853	29	800	28 1/2
21	441	3528	2352	48 1/2	2016	45	1764	42	1568	39 1/2	1412	37 1/2	1282	35 1/2	1176	34	1085	33	1008	31 1/2	940	30 1/2	882	29 1/2
22	484	3872	2581	50 1/2	2212	47	1936	44	1720	41 1/2	1548	39 1/2	1408	37 1/2	1290	35 1/2	1191	34 1/2	1106	33	1032	32	968	31
23	529	4232	2821	53	2418	49	2116	46	1880	43 1/2	1692	41	1538	39	1410	37 1/2	1302	36	1209	34 1/2	1128	33 1/2	1058	32 1/2
24	576	4608	3072	55 1/2	2633	51 1/2	2304	48	2048	45 1/2	1845	43	1675	41	1536	39	1417	37 1/2	1316	36 1/2	1228	35	1152	33 1/2
25	625	5000	3333	57 1/2	2857	53 1/2	2500	50	2222	47	2000	44 1/2	1818	42 1/2	1666	40 1/2	1538	39	1428	37 1/2	1333	36 1/2	1250	35
26	676	5408	3605	60	3090	55 1/2	2704	52	2403	48 1/2	2163	46 1/2	1966	44 1/2	1802	42 1/2	1664	40 1/2	1545	39 1/2	1442	38	1352	36 1/2
27	729	5832	3886	62 1/2	3332	57 1/2	2916	54	2592	50 1/2	2332	48 1/2	2120	46	1944	44	1794	42 1/2	1666	40 1/2	1555	39 1/2	1458	37 1/2
28	784	6272	4181	64 1/2	3584	59 1/2	3136	56	2787	52 1/2	2508	50	2280	47 1/2	2090	45 1/2	1929	44	1792	42 1/2	1672	41	1568	39 1/2
29	841	6728	4485	67	3844	61 1/2	3364	58	2990	54 1/2	2691	51 1/2	2446	49 1/2	2242	47 1/2	2069	45 1/2	1922	43 1/2	1794	42 1/2	1682	41
30	900	7200	4800	69 1/2	4114	64	3600	60	3200	56 1/2	2880	53 1/2	2618	51	2400	49	2215	47	2057	45 1/2	1920	44	1800	42 1/2
31	961	7688	5125	71 1/2	4393	66	3844	62	3417	58 1/2	3075	55 1/2	2795	52 1/2	2562	50 1/2	2365	48 1/2	2196	46 1/2	2050	45 1/2	1922	43 1/2
32	1024	8192	5461	74	4681	68 1/2	4096	64	3640	60 1/2	3276	57 1/2	2989	54 1/2	2730	52 1/2	2520	50	2340	48 1/2	2184	46 1/2	2048	45 1/2
33	1089	8712	5808	76 1/2	4978	70 1/2	4356	66	3872	62 1/2	3484	59	3168	56 1/2	2904	54	2680	51 1/2	2489	50	2323	48	2178	46 1/2
34	1156	9248	6165	78 1/2	5284	72 1/2	4624	68	4110	64 1/2	3699	60 1/2	3362	58	3082	55 1/2	2845	53	2642	51 1/2	2466	49 1/2	2312	48
35	1225	9800	6533	81	5600	74 1/2	4900	70	4355	66	3920	62 1/2	3563	59 1/2	3266	57	3015	54 1/2	2800	53	2613	51	2450	49 1/2
36	1296	10368	6912	83 1/2	5924	77	5184	72	4608	68	4147	64 1/2	3770	61 1/2	3456	58 1/2	3190	56 1/2	2962	54 1/2	2764	52 1/2	2591	51
37	1369	10952	7301	85 1/2	6258	79 1/2	5476	74	4867	69 1/2	4380	66 1/2	3982	63	3650	60 1/2	3308	58	3129	56	2920	53 1/2	2738	52 1/2
38	1444	11559	7713	87 1/2	6601	80 1/2	5776	76	5134	71 1/2	4620	68	4200	64 1/2	3850	62	3554	59 1/2	3300	57 1/2	3080	55 1/2	2888	53 1/2
39	1521	12168	8112	90	6953	83	6084	78	5408	73 1/2	4867	69 1/2	4424	66 1/2	4056	63 1/2	3744	61	3476	59	3244	57	3042	54 1/2
40	1600	12800	8533	92 1/2	7314	85 1/2	6400	80	5688	75 1/2	5120	71 1/2	4654	68 1/2	4266	65 1/2	3938	62 1/2	3657	60 1/2	3413	58 1/2	3200	56 1/2
41	1681	13448	8965	94 1/2	7684	87 1/2	6724	82	5976	77 1/2	5379	73 1/2	4890	70	4462	66 1/2	4137	64	3842	62	3586	59 1/2	3362	58
42	1764	14112	9408	97	8064	89 1/2	7056	84	6272	79 1/2	5644	75	5131	71 1/2	4704	68 1/2	4342	65 1/2	4032	63 1/2	3763	61 1/2	3528	59 1/2
43	1849	14792	9861	99 1/2	8453	92	7396	86	6574	81	5916	76 1/2	5378	73 1/2	4930	70 1/2	4520	67 1/2	4226	65	3944	62 1/2	3698	60 1/2
44	1936	15488	10325	101 1/2	8850	94	7744	88	6883	83	6195	78 1/2	5632	75	5162	71 1/2	4765	69	4425	66 1/2	4130	64	3872	62 1/2
45	2025	16200	10800	104	9257	96 1/2	8100	90	7200	85	6480	80 1/2	5890	76 1/2	5400	73 1/2	4984	70 1/2	4628	68	4320	65 1/2	4050	63 1/2
46	2116	16928	11285	106 1/2	9673	98 1/2	8464	92	7523	86 1/2	6771	82 1/2	6155	78 1/2	5642	75	5208	72 1/2	4836	69 1/2	4514	67	4232	65
47	2209	17672	11781	108 1/2	10098	100 1/2	8836	94	7854	88 1/2	7068	84	6426	80	5890	76 1/2	5437	73 1/2	5049	71	4712	68 1/2	4418	66 1/2
48	2304	18432	12288	110 1/2	10532	102 1/2	9216	96	8192	90 1/2	7372	85 1/2	6702	81 1/2	6144	78	5671	75 1/2	5266	72 1/2	4915	70	4608	68
49	2401	19208	12805	113	10976	104 1/2	9604	98	8536	92	7683	87 1/2	6984	83 1/2	6402	80	5910	77	5488	74	5122	71 1/2	4802	69 1/2
50	2500	20000	13333	115 1/2	11428	106 1/2	10000	100	8888	94	8000	89 1/2	7272	85 1/2	6666	81 1/2	6153	78 1/2	5714	75 1/2	5333	73	5000	71
51	2601	20808	13872	117 1/2	11888	109	10404	102	9248	96 1/2	8323	91 1/2	7566	87	6936	83 1/2	6403	80	5945	77	5548	74 1/2	5202	72 1/2
52	2704	21632	14421	120	12361	111	10816	104	9614	98	8652	93	7866	88 1/2	7210	85	6656	81 1/2	6180	78 1/2	5768	76	5408	73 1/2
53	2809	22472	14981	122 1/2	12841	113 1/2	11236	106	9987	100	8988	94 1/2	8135	90 1/2	7490	86 1/2	6914	83	6420	80	5992	77 1/2	561	75
54	2916	23328	15552	124 1/2	13330	115 1/2	11664	108	10368	101 1/2	9331	96 1/2	8482	92	7776	88 1/2	7116	84 1/2	6665	81 1/2	6220	79	5732	76 1/2
55	3025	24200	16133	127	13828	117 1/2	12100	110	10755	103 1/2	9680	98	8800	93 1/2	8066	89 1/2	7446	86 1/2	6914	83	6453	80 1/2	6050	78
56	3136	25088	16725	129 1/2	14336	119 1/2	12544	112	11150	105 1/2	10035	100	9122	95 1/2	8362	91 1/2	7719	87 1/2	7168	84 1/2	6690	82	6272	79 1/2
57	3249	25992	17328	131 1/2	14852	121 1/2	12996	114	11552	107 1/2	10396	101 1/2	9451	97 1/2	8664	93	7997	89 1/2	7426	86	6931	83 1/2	6408	80 1/2
58	3364	26912	17940	134	15378	124	13456	116	11960	109 1/2	10764	103 1/2	9786	98 1/2	8970	94 1/2	8280	91	7689	87 1/2	7176	84 1/2	6728	82
59	3481	27848	18565	136 1/2	15908	126	13924	118	12376	111 1/2	11139	105 1/2	10126	100 1/2	9282	96 1/2	8568	92 1/2	7956	89	7426	86	6962	83 1/2
60	3600	28800	19200	138 1/2	16457	128 1/2	14400	120	12800	113	11520	107 1/2	10472	102 1/2	9600	98	8861	94 1/2	8228	90 1/2	7680	87 1/2	7200	85
61	3721	29768	19845	140 1/2	17010	130 1/2	14884	122	13230	114 1/2	11907	109	10824	104	9922	99 1/2	9159	95 1/2	8505	92	7938	89	7442	86 1/2
62	3844	30752	20381	142 1/2	17572	132 1/2	15376	124	13676	117	12308	111	11182	105 1/2	10250	101 1/2	9462	97 1/2	8786	93 1/2	8220	90 1/2	7788	87 1/2
63	3969	31752	21168	145	18144	134 1/2	15876	126	14112	119	12700	112 1/2	11454	107 1/2	10584	102 1/2	9769	98 1/2	9072	95 1/2	8467	92	7938	89
64	4096	32768	21845	147 1/2	18724	136 1/2	16384																	

BLOWING OF GLASS

TABLE V. of Blowing Cylinders, their Area, Capacity, and Quantity of Air, discharged by an Eight-Foot Stroke.

Number of Cylinders	Area in Circular Inches.	Area in Square Inches.	Capacity of the Stroke in Cubical Feet.	Air discharged at the Rate of 30 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 40 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 50 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 60 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 70 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 80 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 90 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 100 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 110 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 120 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 130 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 140 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 150 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 160 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 170 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 180 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 190 Cylinders per Minute in Cubical Feet.	Air discharged at the Rate of 200 Cylinders per Minute in Cubical Feet.
35	1296	1017.8784	56.5488	2827.4400	2261.9520	1696.6400	1413.7200	1130.9760	848.2320	678.5856	565.4880										
37	1369	1075.8670	59.7340	2986.7000	2389.3600	1792.0200	1493.3500	1194.6800	896.0100	756.8080	597.3400										
38	1444	1134.1176	61.0064	3150.3200	2520.2560	1890.1920	1575.1600	1260.1280	945.0960	756.0768	630.0640										
39	1521	1194.5934	66.3662	3318.3100	2654.6480	1990.9860	1659.1550	1327.3240	995.4930	796.3944	663.6620										
40	1600	1256.6400	69.8110	3490.5500	2792.4400	2094.3300	1745.2750	1396.2200	1047.1650	837.7320	698.1100										
41	1681	1320.2574	73.3476	3667.3800	2933.9040	2200.4280	1833.6900	1466.9520	1100.2140	880.1712	733.4760										
42	1764	1385.4456	76.9068	3848.3400	3078.6720	2309.0040	1924.1700	1539.3360	1154.5020	921.6016	769.6680										
43	1849	1452.2046	80.6780	4033.9000	3227.1200	2420.3400	2016.9500	1613.5600	1210.1700	968.1360	806.7800										
44	1936	1520.5344	84.4740	4233.7000	3378.9600	2534.2200	2116.8500	1689.4800	1267.1100	1013.6880	844.7400										
45	2025	1590.4350	88.3574	4417.8700	3534.2960	2650.7220	2208.9350	1767.1480	1325.3610	1062.4488	883.5740										
46	2116	1661.9064	92.3280	4616.4000	3693.1200	2769.8400	2308.2000	1846.5600	1384.9200	1107.9360	923.2800										
47	2209	1734.9486	96.3860	4819.3000	3855.4400	2891.5800	2409.6500	1927.7200	1445.7900	1156.6320	963.8608										
48	2304	1809.5616	100.5312	5026.5600	4021.2480	3015.9360	2513.2800	2010.6240	1507.9680	1206.3744	1003.3120										
49	2401	1885.7545	104.7036	5238.1800	4190.5440	3142.9080	2619.0900	2095.2720	1571.4540	1255.1032	1047.6360										
50	2500	1963.5000	109.0832	5454.1600	4363.3880	3272.4960	2727.0800	2181.6940	1636.2480	1308.9984	1090.8470										
51	2601	2042.8254	113.4902	5674.5100	4539.6080	3404.7060	2837.2550	2269.8040	1702.3530	1361.8824	1134.9020										
52	2704	2123.7216	117.9288	5896.4400	4717.1520	3537.8640	2948.2200	2358.5760	1768.9320	1415.1456	1179.2880										
53	2809	2206.1886	122.5660	6128.3000	4902.6400	3676.9800	3064.1500	2451.3200	1838.4900	1470.7920	1225.6600										
54	2916	2290.2264	127.2346	6361.7300	5089.3840	3817.0380	3180.8650	2544.6920	1908.5190	1526.8152	1272.3460										
55	3025	2375.8350	131.9908	6599.5400	5279.6320	3959.7240	3299.7700	2639.8160	1979.8620	1583.8896	1319.9080										
56	3136	2463.0144	136.8034	6840.1700	5472.1360	4104.1020	3420.0850	2736.0680	2052.0510	1641.6438	1368.0340										
57	3249	2551.7646	141.7646	7088.2300	5670.5840	4252.9380	3544.1150	2835.2920	2126.9690	1701.1752	1417.6460										
58	3364	2642.0856	146.7826	7339.1300	5871.3040	4403.4780	3669.5650	2935.6520	2201.7390	1751.3912	1467.8260										
59	3481	2733.9774	151.8876	7594.3800	6075.5040	4556.6280	3797.1900	3037.7520	2278.3140	1812.6312	1518.8760										
60	3600	2827.4400	157.0800	7854.0000	6283.2000	4712.4000	3927.0000	3141.6000	2356.2000	1884.9600	1570.8000										
61	3721	2922.4734	162.3596	8117.9800	6494.3840	4870.7880	4058.9900	3247.1920	2435.3940	1948.3152	1623.5960										
62	3844	3019.0776	167.7264	8386.3200	6709.0560	5031.7920	4193.1600	3354.5280	2515.8960	2012.7168	1677.2640										
63	3969	3117.2526	173.1406	8657.0300	6925.6240	5194.2180	4328.5150	3462.8120	2597.1040	2077.6872	1731.4010										
64	4096	3216.9984	178.6664	8933.3200	7146.6560	5359.9920	4466.6600	3573.3280	2679.9960	2144.1968	1786.6640										
65	4225	3318.3150	184.3508	9217.5400	7374.0320	5530.5240	4608.7700	3687.0160	2765.2620	2212.2096	1843.5080										
66	4356	3421.2024	190.0668	9503.3400	7602.6720	5702.0040	4751.6700	3801.3360	2851.0020	2280.8016	1900.1680										
67	4489	3525.6606	195.8700	9793.5000	7834.8000	5876.1000	4896.7500	3917.4000	2938.0000	2350.4400	1958.7000										
68	4624	3631.6896	201.7604	10088.0200	8070.4160	6052.8120	5044.0100	4035.2080	3026.4060	2421.1248	2017.6040										
69	4761	3739.2394	207.7382	10386.9100	8309.5280	6232.1460	5193.4550	4154.7640	3116.0730	2492.8584	2077.3820										
70	4900	3848.4600	213.8034	10690.1700	8552.1360	6414.1020	5345.8050	4276.0680	3207.0510	2565.6408	2138.0340										
71	5041	3959.2014	219.9556	10997.7800	8798.2240	6598.6680	5498.8900	4399.1120	3299.3340	2639.4672	2199.5560										
72	5184	4071.5136	226.1952	11309.7600	9047.8080	6785.8560	5654.8800	4523.9040	3392.9280	2714.3424	2261.9520										
73	5329	4185.9966	232.5220	11626.1000	9300.8800	6975.6600	5813.0500	4650.4400	3487.8300	2790.2640	2325.2200										
74	5476	4300.8504	238.9360	11946.8000	9557.4400	7168.0800	5973.4000	4778.7200	3584.0400	2876.2320	2389.3600										
75	5625	4417.8750	245.4374	12271.8700	9817.4960	7363.1220	6135.9350	4908.7480	3681.0610	2945.2488	2454.3740										
76	5776	4536.4704	252.0260	12601.3000	10081.0400	7560.7800	6300.6500	5040.5200	3780.3900	3024.3126	2520.2600										
77	5929	4656.6366	258.6464	12932.3200	10345.8560	7759.3920	6466.1600	5172.9280	3879.6960	3103.7568	2586.6400										
78	6084	4778.3736	265.4652	13273.2600	10616.8680	7963.9560	6636.6300	5309.3040	3981.9780	3185.5824	2654.6520										
79	6241	4901.6814	272.3156	13615.7800	10892.6240	8169.4680	6807.8900	5446.3120	4084.7340	3267.7872	2723.1560										
80	6400	5026.5600	279.2530	13962.6500	11170.1200	8377.5900	6981.3250	5585.0600	4188.7950	3351.0360	2792.5300										
81	6561	5153.0094	286.2782	14313.9100	11451.1280	8588.3460	7156.9550	5725.5640	4294.1730	3435.3834	2862.8720										
82	6724	5281.0296	293.3904	14669.5200	11735.6160	8801.7120	7334.7600	5867.8080	4400.8560	3520.6848	2933.9040										
83	6889	5410.6206	300.5900	15029.5000	12023.6000	9017.7000	7514.7500	6011.8000	4508.8500	3607.0800	3005.9000										
84	7056	5541.7824	307.8772	15393.8600	12315.0880	9236.3160	7696.9300	6157.5440	4618.1580	3694.5264	3078.2720										
85	7225	5674.5104	315.2508	15752.5400	12610.0320	9457.5240	7881.2700	6305.0160	4728.2660	3783.0096	3152.5080										
86	7396	5808.8184	322.7120	16135.6000	12908.4800	9681.3600	8067.8000	6454.2400	4840.6800	3872.5440	3227.1200										
87	7569	5944.6926	330.2606	16513.0300	13210.4240	9927.8180	8256.0150	6605.3120	4953.9090	3963.1272	3327.6060										
88	7744	6082.1376	337.8964	16894.8200	13515.8560	10136.8920	8447.4120	6757.4280	5068.4460	4054.7568	3378.7140										
89	7921	6221.1534	345.6196	17280.9800	13824.7840	10368.5880	8640.4900	6912.1920	5184.2940	4147.4352	3456.1960										
90	8100	6361.7400	353.4300	17671.5000	14137.2000	10602.9000	8835.7500	7068.6000	5301.4500	4241.1600	3534.3000										
91	8281	6503.8974	361.3276	18066.3800	14453.1040	10839.8280	9033.1900	7226.5520	5419.9140	4335.9312	3613.2760										
92	8464	6647.6256	369.3124	18466.6200	14772.4960	11079.3720	9232.8100	7386.2480	5539.6860	4431.7488	3693.1240										
93	8649	6792.9246	377.3846	18869.2300	15095.3840	11321.5380	9434.6150	7547.6920	5660.7690	4528.6152	3773.8460										
94	8836	6939.7944	385.5440	19277.2000	15421.7600	11566.3200	9638.2000	7710.8800	5783.1600	4626.5280	3855.4400										

BLOWING OF GLASS

TABLE VI. of the Powers of Steam Engines working at the Rate of 10lbs. Avoirdupoise upon every Circular Inch, or 12.73 lbs. upon every Square Inch of the Steam Piston applicable to Blowing Machinery; and the Areas and Diameters of Blowing Cylinders requisite to raise Air of various Densities from 1 $\frac{1}{2}$ lb. to 4lbs. Avoirdupoise upon each Circular Inch, or from 1.90lb. to 5.09lbs. upon each Square Inch of the Air Receiver.

Steam Cyl.	Area of Steam Cyl.	Blow 1 lb. per Circular Inch, or 1.90 lb. per Square Inch.	Blow 1 $\frac{1}{2}$ lb. per Circular Inch, or 2.85 lb. per Square Inch.	Blow 2 lb. per Circular Inch, or 3.80 lb. per Square Inch.	Blow 2 $\frac{1}{2}$ lb. per Circular Inch, or 4.75 lb. per Square Inch.	Blow 3 lb. per Circular Inch, or 5.70 lb. per Square Inch.	Blow 3 $\frac{1}{2}$ lb. per Circular Inch, or 6.65 lb. per Square Inch.	Blow 4 lb. per Circular Inch, or 7.60 lb. per Square Inch.	Blow 4 $\frac{1}{2}$ lb. per Circular Inch, or 8.55 lb. per Square Inch.	Blow 5 lb. per Circular Inch, or 9.50 lb. per Square Inch.	Blow 5 $\frac{1}{2}$ lb. per Circular Inch, or 10.45 lb. per Square Inch.	Blow 6 lb. per Circular Inch, or 11.40 lb. per Square Inch.	Blow 6 $\frac{1}{2}$ lb. per Circular Inch, or 12.35 lb. per Square Inch.	Blow 7 lb. per Circular Inch, or 13.30 lb. per Square Inch.	Blow 7 $\frac{1}{2}$ lb. per Circular Inch, or 14.25 lb. per Square Inch.	Blow 8 lb. per Circular Inch, or 15.20 lb. per Square Inch.	Blow 8 $\frac{1}{2}$ lb. per Circular Inch, or 16.15 lb. per Square Inch.	Blow 9 lb. per Circular Inch, or 17.10 lb. per Square Inch.	Blow 9 $\frac{1}{2}$ lb. per Circular Inch, or 18.05 lb. per Square Inch.	Blow 10 lb. per Circular Inch, or 19.00 lb. per Square Inch.	
		Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.	Area of blowing Cylinder.	Diameter of Ditto.
20	400	2666	51 $\frac{1}{2}$	2285	47 $\frac{1}{2}$	2000	44 $\frac{1}{2}$	1777	42	1600	40	1454	38	1333	36 $\frac{1}{2}$	1230	35	1142	34	1066	32 $\frac{1}{2}$
21	441	2949	54 $\frac{1}{2}$	2520	50 $\frac{1}{2}$	2205	47 $\frac{1}{2}$	1960	44 $\frac{1}{2}$	1764	42	1603	40	1470	38 $\frac{1}{2}$	1356	36 $\frac{1}{2}$	1260	35 $\frac{1}{2}$	1176	34 $\frac{1}{2}$
22	484	3236	57	2765	52 $\frac{1}{2}$	2420	49 $\frac{1}{2}$	2151	46 $\frac{1}{2}$	1936	44	1760	42	1613	40	1489	38 $\frac{1}{2}$	1382	37	1290	36
23	529	3526	59 $\frac{1}{2}$	3022	55	2645	51 $\frac{1}{2}$	2351	48 $\frac{1}{2}$	2116	46	1923	44	1763	42	1627	40 $\frac{1}{2}$	1511	38 $\frac{1}{2}$	1410	37 $\frac{1}{2}$
24	576	3840	62	3291	57 $\frac{1}{2}$	2880	53 $\frac{1}{2}$	2560	50 $\frac{1}{2}$	2304	48	2094	43 $\frac{1}{2}$	1920	44	1772	42	1645	40 $\frac{1}{2}$	1536	39 $\frac{1}{2}$
25	625	4160	64 $\frac{1}{2}$	3571	59 $\frac{1}{2}$	3125	56	2777	52 $\frac{1}{2}$	2500	50	2272	47	2083	45 $\frac{1}{2}$	1923	44	1785	42	1666	40 $\frac{1}{2}$
26	676	4506	67	3862	62	3380	58 $\frac{1}{2}$	3004	53 $\frac{1}{2}$	2704	52	2458	49	2253	47 $\frac{1}{2}$	2080	45 $\frac{1}{2}$	1931	44	1802	42 $\frac{1}{2}$
27	729	4860	69 $\frac{1}{2}$	4165	64 $\frac{1}{2}$	3645	60 $\frac{1}{2}$	3240	57	2916	54	2650	51 $\frac{1}{2}$	2430	49 $\frac{1}{2}$	2243	47 $\frac{1}{2}$	2082	45 $\frac{1}{2}$	1941	44
28	784	5226	72	4480	67	3920	62 $\frac{1}{2}$	3484	59	3136	56	2850	53 $\frac{1}{2}$	2613	51	2414	49	2240	47 $\frac{1}{2}$	2090	45 $\frac{1}{2}$
29	841	5606	74 $\frac{1}{2}$	4805	69 $\frac{1}{2}$	4205	64 $\frac{1}{2}$	3737	61	3364	58	3058	55 $\frac{1}{2}$	2803	53	2587	50 $\frac{1}{2}$	2402	49	2242	47 $\frac{1}{2}$
30	900	6000	77 $\frac{1}{2}$	5142	71 $\frac{1}{2}$	4500	67	4000	63	3600	60	3272	57 $\frac{1}{2}$	3000	54 $\frac{1}{2}$	2769	52 $\frac{1}{2}$	2571	50 $\frac{1}{2}$	2400	49
31	961	6406	80	5491	74	4805	69 $\frac{1}{2}$	4271	65 $\frac{1}{2}$	3844	62	3494	59	3203	56 $\frac{1}{2}$	2958	54 $\frac{1}{2}$	2745	52 $\frac{1}{2}$	2562	50 $\frac{1}{2}$
32	1024	6826	82 $\frac{1}{2}$	5851	76 $\frac{1}{2}$	5120	71 $\frac{1}{2}$	4560	67 $\frac{1}{2}$	4096	64	3723	61	3413	58 $\frac{1}{2}$	3150	56	2925	54	2730	52 $\frac{1}{2}$
33	1089	7260	85 $\frac{1}{2}$	6222	79	5495	74	4842	69 $\frac{1}{2}$	4356	66	3960	63	3630	60 $\frac{1}{2}$	3350	58	3111	55 $\frac{1}{2}$	2904	54
34	1156	7706	87 $\frac{1}{2}$	6605	81 $\frac{1}{2}$	5780	76	5137	71 $\frac{1}{2}$	4624	68	4203	65	3853	62	3556	59 $\frac{1}{2}$	3302	57 $\frac{1}{2}$	3082	55 $\frac{1}{2}$
35	1225	8166	90 $\frac{1}{2}$	6999	84 $\frac{1}{2}$	6125	78 $\frac{1}{2}$	5444	73 $\frac{1}{2}$	4900	70	4454	67	4083	64	3781	61 $\frac{1}{2}$	3500	59 $\frac{1}{2}$	3266	57
36	1296	8640	93	7405	86	6480	80 $\frac{1}{2}$	5760	76	5184	72	4712	68 $\frac{1}{2}$	4320	65 $\frac{1}{2}$	3987	63	3702	61	3456	58 $\frac{1}{2}$
37	1369	9126	95 $\frac{1}{2}$	7822	88 $\frac{1}{2}$	6845	83	6084	78	5476	74	4978	70 $\frac{1}{2}$	4653	67 $\frac{1}{2}$	4212	65	3911	62 $\frac{1}{2}$	3650	60 $\frac{1}{2}$
38	1444	9626	98	8251	90 $\frac{1}{2}$	7220	85	6417	80	5776	76	5250	72 $\frac{1}{2}$	4813	69 $\frac{1}{2}$	4443	66 $\frac{1}{2}$	4125	64	3850	62
39	1521	10140	100 $\frac{1}{2}$	8691	93 $\frac{1}{2}$	7605	87 $\frac{1}{2}$	6760	82 $\frac{1}{2}$	6084	78	5530	74 $\frac{1}{2}$	5070	71 $\frac{1}{2}$	4680	68 $\frac{1}{2}$	4345	66	4056	63 $\frac{1}{2}$
40	1600	10666	103	9142	95 $\frac{1}{2}$	8000	89 $\frac{1}{2}$	7111	84 $\frac{1}{2}$	6400	80	5818	76 $\frac{1}{2}$	5333	73	4920	70	4571	67 $\frac{1}{2}$	4266	65 $\frac{1}{2}$
41	1681	11206	105 $\frac{1}{2}$	9605	98	8405	91 $\frac{1}{2}$	7471	86 $\frac{1}{2}$	6724	82	6112	78 $\frac{1}{2}$	5603	75	5172	72	4802	69 $\frac{1}{2}$	4482	67
42	1764	11760	108 $\frac{1}{2}$	10080	100 $\frac{1}{2}$	8820	94	7840	88 $\frac{1}{2}$	7056	84	6414	80	5880	76 $\frac{1}{2}$	5427	73 $\frac{1}{2}$	5040	71	4794	68 $\frac{1}{2}$
43	1849	12326	111	10565	102 $\frac{1}{2}$	9245	96	8217	90 $\frac{1}{2}$	7396	86	6723	82	6163	78 $\frac{1}{2}$	5689	75 $\frac{1}{2}$	5282	72 $\frac{1}{2}$	4930	70
44	1936	12906	113 $\frac{1}{2}$	11062	105	9680	98 $\frac{1}{2}$	8604	92 $\frac{1}{2}$	7744	88	7040	84	6453	80 $\frac{1}{2}$	5956	77 $\frac{1}{2}$	5531	74 $\frac{1}{2}$	5162	72 $\frac{1}{2}$
45	2025	13500	116 $\frac{1}{2}$	11571	107 $\frac{1}{2}$	10125	100 $\frac{1}{2}$	9080	95	8100	90	7363	85 $\frac{1}{2}$	6750	82	6220	79	5785	76	5400	73 $\frac{1}{2}$
46	2116	14106	118 $\frac{1}{2}$	12091	110	10580	102 $\frac{1}{2}$	9404	97	8464	92	7694	87 $\frac{1}{2}$	7053	84	6510	80 $\frac{1}{2}$	6045	77 $\frac{1}{2}$	5642	75 $\frac{1}{2}$
47	2209	14726	121 $\frac{1}{2}$	12622	112 $\frac{1}{2}$	11045	105	9817	99	8836	94	8032	89 $\frac{1}{2}$	7363	86	6798	82 $\frac{1}{2}$	6311	79 $\frac{1}{2}$	5890	76 $\frac{1}{2}$
48	2304	15360	124	13166	114 $\frac{1}{2}$	11520	107	10244	101 $\frac{1}{2}$	9216	96	8378	91 $\frac{1}{2}$	7680	87 $\frac{1}{2}$	7049	84 $\frac{1}{2}$	6582	81	6144	78 $\frac{1}{2}$
49	2401	16006	126 $\frac{1}{2}$	13720	117	12005	109 $\frac{1}{2}$	10671	103 $\frac{1}{2}$	9605	98	8730	93 $\frac{1}{2}$	8003	89 $\frac{1}{2}$	7387	86	6860	82 $\frac{1}{2}$	6402	80
50	2500	16666	129	14285	119 $\frac{1}{2}$	12500	111 $\frac{1}{2}$	11111	105 $\frac{1}{2}$	10000	100	9090	95 $\frac{1}{2}$	8333	91 $\frac{1}{2}$	7692	87 $\frac{1}{2}$	7142	84 $\frac{1}{2}$	6666	81 $\frac{1}{2}$
51	2601	17340	131 $\frac{1}{2}$	14862	122	13005	114	11560	107 $\frac{1}{2}$	10404	102	9458	97 $\frac{1}{2}$	8670	93	8003	89 $\frac{1}{2}$	7431	86	6936	83 $\frac{1}{2}$
52	2704	18026	134	15451	124 $\frac{1}{2}$	13520	116 $\frac{1}{2}$	12017	109 $\frac{1}{2}$	10816	104	9832	99	9013	95	8320	91 $\frac{1}{2}$	7725	87 $\frac{1}{2}$	7210	85
53	2809	18726	136 $\frac{1}{2}$	16051	126 $\frac{1}{2}$	14045	118 $\frac{1}{2}$	12484	111 $\frac{1}{2}$	11236	106	10214	101	9363	96 $\frac{1}{2}$	8643	93	8025	89 $\frac{1}{2}$	7490	86 $\frac{1}{2}$
54	2916	19440	139 $\frac{1}{2}$	16662	129	14580	120 $\frac{1}{2}$	12960	113 $\frac{1}{2}$	11664	108	10603	103	9720	98 $\frac{1}{2}$	8972	94 $\frac{1}{2}$	8331	91 $\frac{1}{2}$	7776	88 $\frac{1}{2}$
55	3025	20166	142	17285	131 $\frac{1}{2}$	15125	123	13444	116	12100	110	11000	105	10832	100 $\frac{1}{2}$	9307	96	8642	93	8066	89 $\frac{1}{2}$
56	3136	20906	144 $\frac{1}{2}$	17929	133 $\frac{1}{2}$	15680	125 $\frac{1}{2}$	13937	118	12544	112	11403	106 $\frac{1}{2}$	10453	102	9649	98 $\frac{1}{2}$	8960	94 $\frac{1}{2}$	8362	91 $\frac{1}{2}$
57	3249	21660	147 $\frac{1}{2}$	18595	136 $\frac{1}{2}$	16245	127 $\frac{1}{2}$	14440	120	12996	114	11814	108 $\frac{1}{2}$	10830	104	9997	100	9282	96 $\frac{1}{2}$	8664	93
58	3364	22426	149 $\frac{1}{2}$	19222	138 $\frac{1}{2}$	16820	129 $\frac{1}{2}$	14951	122	13456	116	12232	110 $\frac{1}{2}$	11214	106	10350	102 $\frac{1}{2}$	9611	98	8970	94 $\frac{1}{2}$
59	3481	23210	152 $\frac{1}{2}$	19861	141 $\frac{1}{2}$	17405	132	1542	124	13924	118	12658	112 $\frac{1}{2}$	11603	107 $\frac{1}{2}$	10710	103 $\frac{1}{2}$	9943	99 $\frac{1}{2}$	9282	96 $\frac{1}{2}$
60	3600	24000	155	20571	143 $\frac{1}{2}$	18000	134 $\frac{1}{2}$	16000	126	14400	120	13098	114 $\frac{1}{2}$	12000	109 $\frac{1}{2}$	11077	105 $\frac{1}{2}$	10285	101 $\frac{1}{2}$	9600	98
61	3721	24806	157 $\frac{1}{2}$	21252	145 $\frac{1}{2}$	18605	136 $\frac{1}{2}$	16537	128	14884	122	13530	116 $\frac{1}{2}$	12403	111 $\frac{1}{2}$	11449	107	10631	102 $\frac{1}{2}$	9922	99 $\frac{1}{2}$
62	3844	25626	160	21965	148 $\frac{1}{2}$	19220	138 $\frac{1}{2}$	17084	130 $\frac{1}{2}$	15376	124	13971	118 $\frac{1}{2}$	12813	113 $\frac{1}{2}$	11827	108 $\frac{1}{2}$	10982	104 $\frac{1}{2}$	10250	100 $\frac{1}{2}$
63	3969	26460	162 $\frac{1}{2}$	22622	150 $\frac{1}{2}$	19845	140 $\frac{1}{2}$	17640	132 $\frac{1}{2}$	15876	126	14436	120	13230	115	12212	110 $\frac{1}{2}$	11340	106 $\frac{1}{2}$	10584	103
64	4096	27306	165 $\frac{1}{2}$	23340	153	20480	143	18204	135	16384	128	14894	122	13653	117	12603	112 $\frac{1}{2}$	11702	108	10922	104 $\frac{1}{2}$
65	4225	28166	168 $\frac{1}{2}$	24122	155 $\frac{1}{2}$	21125	145 $\frac{1}{2}$	18777	137	16900	130	15363	124	14083	118 $\frac{1}{2}$	13000	114	12071	109 $\frac{1}{2}$	11266	106
66	4356	29040	170 $\frac{1}{2}$	24891	157 $\$																

Boiler

BOILER, or BOYLER, a large copper vessel, wherein things are exposed over the fire to be boiled.

The boiler, in the alum-works, is a vessel, in which the liquor is evaporated to a consistence, and is made of lead.

The general size is about eight feet square, and they contain about twelve tons each.

They make them in this manner: first, they lay long pieces of cast-iron, twelve inches square, as long as the

breadth of the boiler, and at about twelve inches distance from one another. These are placed twenty-four inches above the surface of the fire. On these massy bars of iron they lay, cross-wise, the common flat bars of iron, as close as they can lie together, and then make up the sides with brick-work. In the middle of the bottom of this boiler is laid a trough of lead, wherein they put at first about a hundred pound weight of the rock. They use Newcastle coals in the boiling; and if they find the liquor not strong enough, they add more of the rock at times, as it boils. Phil. Trans. N^o 142.

The boiler for making colours, &c. must be made of pewter; because iron and copper will be corroded by the saline substances used in the manufacture of them.

Count Rumford (See his *Essays*, vol. i. p. 220.) recommends double bottoms to boilers, and also to saucepans and kettles of all kinds, used for culinary purposes; which contrivance, he says, will, in all cases, most effectually prevent what is called by the cooks, "burning-to." The heat is so much obstructed in its passage through the thin sheet of air which, notwithstanding all the care that is taken to bring the two bottoms into actual contact, will still remain between them, that the second has time to give its heat as fast as it receives it to the fluid in the boiler; and consequently it never requires a degree of heat sufficient for burning any thing that may be upon it. He suggests that it will probably be best to double copper saucepans and small kettles throughout; and as this may and ought to be done with a very thin sheet of metal, it would not cost much, even if the lining were to be made of silver. When the two sheets of metal that form the double bottoms of boilers are made to touch each other throughout, by hammering them together after the false bottom has been fixed in its place, they may be tacked together by a few small rivets placed here and there, at considerable distances from each other; and when this is done, the boiler may be tinned. In this operation, if proper care be taken, the edge of the false bottom may be soldered by the tin to the sides of the boiler, and thus the water or other liquids, put into the boiler, will be prevented from getting between the two bottoms. The Count adds, that this invention of double bottoms might be used with great success by distillers, to prevent their liquor, when it is thick, from burning to the bottom of their stills. (See *STILL*.) Having found in the course of his experiments, (See Phil. Trans. 1792, Part I.) that confined air is the best barrier that can be opposed to heat for the purpose of confining it, he proposed to confine the heat in the boilers of his construction, and to prevent its escape into the atmosphere, by means of double covers. These covers were made of tin, or rather of thin iron-plates tinned, in the form of a hollow-cone; the height of the cone being equal to about one-third of its diameter; and thus the air which it contained was entirely shut up, the bottom of the cone being closed by a circular plate or thin sheet of tinned iron. The bottom of the cone was accurately fitted to the top of the boiler, which it completely closed by means of a rim about two inches wide, which entered the boiler; which rim was soldered to the flat sheet of tinned iron that formed the bottom of the cover. The steam, generated by the boiling liquid, was carried off by a tube about half an inch in diameter, which passed through the hollow conical cover, and which was attached to the cover, both above and below, with solder, in such a manner that the air with which the hollow cone was filled remained completely confined, and cut off from all communication with the external air of the atmosphere, as well as with the steam it generated in the boiler. For his various contrivances in the most advan-

tageous construction of boilers for the saving of fuel, and for producing the desired effect, we refer to his *Essays*, vol. ii. p. 18, &c.

BOILERY, or BOILARY, in the *Salt Works*, denotes a salt-house, pit, or other place, where salt is made.

BOILING OF MEAT, in *Cookery*, is the exposing of meat to the heat of boiling water, while it is immersed in it for a certain time. By this joint application of heat and moisture, the texture is rendered more tender and more soluble in the stomach; and it is only in this way, that the firmer parts, as the tendinous, ligamentous, and membranous parts can be duly softened, and their gelatinous substance duly extracted. A moderate boiling renders the texture of animal flesh more tender, without much diminution of its nutritious quality; but if the boiling is extended to extract every thing soluble, the substance remaining becomes less soluble in the stomach, and at the same time much less nutritious. But as boiling extracts in the first place the more soluble, and therefore the saline parts; so the remainder, after boiling, is in proportion to the continuance of the operation less alkaline, and less heating to the system.

Boiling is commonly practised in open vessels, or in vessels not closely covered; but it may be performed in digesters, or vessels accurately and tightly closed; and in such vessels the effects are very different from those that take place in open vessels. As we can hardly employ any other degree of heat than that of boiling water, the water in the digester is never made to boil, so there is no exhalation of volatile parts; and, although the solution is made with great success, and may be to any degree required, yet if it be not carried very far, the meat may be rendered very tender, while it still retains its most sapid parts; and this kind of cookery will always give the most desirable state of boiled meat. Boiling, in the ordinary way, is different, according to the proportion of water that is applied. If a small quantity be applied, and the heat in a moderate degree is continued for a long time, this is called "stewing," and has the effect of rendering the texture more tender, without extracting much of the soluble parts; and of course it leaves the meat more sapid, and sufficiently nourishing. Cullen's *Mat. Med.* vol. i. p. 400, &c.

BOILING, *ebullition*, in *Physics*, is the internal commotion excited in a mass of water or other liquefied substance, by the successive conversion of the lower portions of the fluid into vapour, and their violent effort under this expansive and elastic form to make their escape. It is usually, though not necessarily, produced by the application of heat. The circumstances which precede or accompany the phenomenon of boiling, are best observed in a thin transparent flask nearly filled with water, and suspended over a lamp or a charcoal fire. Numerous minute globules are seen collecting from all points towards the sides and rising in a stream to the surface; occasioned evidently by the discharge of air, which is always in some proportion combined with water. As the heat increases, the liquid particles near the bottom of the flask suddenly burst into steam, and shoot upwards; but in ascending through the colder mass, they again collapse, stop their progress, and seem lost. Such alternate expansions and contractions, by throwing the fluid into a gentle tremor, frequently causes a peculiar sort of singing noise, which is rightly supposed to betoken the approach of actual boiling. This singing is more likely to happen in the case where heat is applied partially; for instance, if a tea-kettle be placed at the side of the fire, since the heat is then more slowly and unequally diffused through the body of the water. But after the whole contents being fully penetrated, are warmed up to the requisite degree of intensity, the steam, as fast as it is

formed, ascends continually and escapes unimpaired through the fluid, which it, therefore, heaves with violent agitation.

The same appearance almost is produced by removing or even diminishing the atmospheric pressure. Thus, if a tumbler holding warm water be introduced under the receiver of an air-pump, as the exhaustion proceeds, or the incumbent weight is gradually withdrawn, the latent portion of air is discharged in a rapid flow of expanded bubbles. But this process, at some certain point of rarefaction, is succeeded by the vehement commotion which constitutes boiling; and the water, assuming its invisible form, fills the imperfect void with vapour, which betrays its existence by condensing against the sides of the receiver in copious dew. Nor is heat positively necessary towards vaporization, for it only conspires in accomplishing that effect, and supplies the want or the imperfection of our means of producing exhaustion. By help of an air-pump of the best construction, the coldest water may be made to boil, nay, ice itself could be changed into invisible steam. Hence the utter impossibility of ever obtaining a perfect vacuum, because the restraining influence of pressure being entirely removed, the liquid matter unavoidably presented would always diffuse a thin vapour.

The opposite influence of heat and pressure on the constitution of fluids is well exhibited by a very simple yet striking experiment. Take a large thin phial, and having warmed it gradually to avoid the risk of cracking the glass, fill it completely with boiling water, cork it tight, and expose it to a current of cold air. As the water cools, it necessarily contracts its volume, and leaving an imperfect vacuum below the neck of the phial, it hence becomes to a considerable degree relieved from the load of atmospheric pressure. It therefore soon begins again to boil, nay, it will boil more briskly the faster it cools; and this singular appearance, so contrary to our usual notions, may continue perhaps for the space of half an hour, till the water has grown as cold almost as the temperature of the human body. On the same principle depends the construction of what is called the *pulse glass*: this consists of two balls connected by a pretty long tube; one of these balls is filled with coloured water or spirits of wine, which having been made to boil and expel the air by its vapour, at the same instant the point projecting from the other ball is hermetically sealed. As that vapour condenses with cold, it will leave the included liquid then in a sort of vacuum, and the heat of the hand is then sufficient to cause it to boil and to flow from one ball into the other.

If a vessel containing water be placed over a steady fire, the water will grow continually hotter till it reaches the limit of boiling, after which the regular accessions of heat are wholly spent in converting it into steam. The water therefore remains at the same pitch of temperature, however fiercely it boils. The only difference is that, with a strong fire, it sooner comes to boil, and more quickly boils away. Hence the reason why a vessel full of water, and plunged into the centre of a larger one, which is likewise filled with that fluid, barely acquires the boiling heat, but will never actually boil.

The formation of steam occasions a prodigious consumption of heat; for if the time be noted in which water, by the action of a strong fire, is raised from the limit of freezing to that of boiling, it will be found to require more than five times longer a space to boil entirely away. Thus, a portion of heat corresponding to above 900 degrees by Fahrenheit's scale, is always consumed in the act of boiling, or rather it is transferred and enters into the composition of steam, the gaseous product. This absorbed heat is as constantly evolved when steam condenses and returns to its liquid form.

Hence in distillation a very large refrigeratory is required for condensing a comparatively small quantity of aqueous or spirituous vapour. Hence too the explication of the familiar remark that steam scalds more cruelly than boiling water.

The heat of boiling water, being subject to the influence of the atmospheric pressure, is thus not absolutely fixed. It varies with the variation of the barometer, and decreases as the mercury descends. The extent of this fluctuation may in our changeable climate amount to five degrees by Fahrenheit's scale, the successive difference of a degree corresponding nearly to each twentieth part of the remaining incumbent weight. On the tops of lofty mountains water will boil much sooner than in the plains below. This curious fact has been noticed by several travellers, and was particularly observed by Saussure on the summit of Mont Blanc. A still greater variation would be experienced on the peak of Chimboraco, the highest point of the Andes, where water would boil with a heat scarcely superior to that which is commonly assigned for the boiling of spirits of wine.

It is therefore evident that, under an augmented pressure, all liquids will more slowly reach the crisis of ebullition and will then have acquired a more intense heat. Thus water may be heated up many degrees above the mean point of boiling, if it be subjected to the action either of condensed air or of confined steam. Such is the principle of *Papin's Digester*; which, being nearly filled with water, is shut perfectly close, and set on a good fire. As the steam so formed is prevented from escaping, it necessarily concentrates, and exerting accumulated energy, it by its prodigious compression enables the water continually to receive additional heat. Nor would this progress at all stop, till the elasticity of the imprisoned vapour comes to surmount every obstacle, and bursts the vessel with terrible explosion. Accidents of that sort are extremely dangerous, and the experiment has consequently never been pushed to its utmost practicable limits. When the fracture takes place, not only the confined steam is liberated, but the pressure being now removed, the excess of heat instantaneously converts a part or the whole of the water likewise into steam, which augments the general effect. This we may perceive in the bursting of a glass cracker; for the little base is shivered into atoms, and the water which it contained is entirely dispersed, beating down flat the wick of the candle by the violence of the sudden expansive blast.

Hence the boiling heat of a deep cauldron is always rather greater than that of a shallow pan. This excess we might estimate at nearly one degree of Fahrenheit, for each foot of depth. The heat of ebullition must also rise somewhat higher, if the steam be not allowed to escape as fast as it is generated; for which reason there may be a slight difference of energy between rapid and slow boiling. Hence by the combined operation of both these causes, water deeply lodged in the bowels of the earth, or concealed under the dark bed of the ocean, is capable of acquiring the most intense heat from the action of subterranean fires; a principle of which Dr. Hutton has ingeniously availed himself in framing his Theory of the Earth.

But the position of the boiling point is likewise modified by the influence of chemical attraction. Thus sugar, common salt, and other saline substances, have all of them a tendency to fix water and retard the crisis of its conversion into elastic vapour. Strong brine will not boil until it is heated up several degrees above the ordinary limit. Hence a vessel containing fresh water, and immersed in another which is filled with brine, will gently boil, while the surrounding fluid only simmers. On the other hand, the addi-

tion of alcohol renders water more volatile. In the distillation of spirits, the fermented liquor in the copper boils always at a lower temperature, or at some intermediate point between the ebullition of water and that of alcohol. The spirituous fumes which rise carry along with them a portion of evaporated water. Hence the necessity of rectification, or repeated distillations, to procure alcohol in its purest state; for the boiling heat is lowered, and consequently the pro-

portion of aqueous admixture is diminished, at each successive process. See DIGESTER, EBULLITION, FIRE, FLUID, HEAT, PRESSURE, STEAM, VAPOUR.

BOILING of *silk with soap*, is the first preparation in order to dyeing it. Thread is also *boiled* in a strong *lixivium* of ashes, to prepare it for dyeing.

Boiling is also a part of the process for bleaching warp linen.

Boring

BORING, the act of perforating a solid body, or making a hole throughout its whole length or thickness.

Surgeons speak of boring the bones of the skull, properly called trepanning.

BORING birch, and other trees, is practised in the spring for their juice, called also *tapping* and *bleeding*. Phil. Traut. N 44. p. 880. See **BERULA**.

BORING, in *Farriery*, an operation formerly practised for the cure of horses whose shoulders are wrenched. The method is thus: they cut a hole through the skin in the middle of the shoulder, and with the shank of a tobacco pipe, blow it as a butcher does a shoulder of veal; then they run a cold flat iron, like a horseman's sword-blade, eight or ten inches up, between the shoulder blade and the ribs, which they call boring; after that they burn him round his shoulder with a hot iron. This, says Bartlett, is an absurd and useless, as well as a cruel practice.

BORING of Cannon, in *Foundry*. See **CANNON**.

BORING of Mast, from top to bottom, is proposed by Dr. Hook, as a means of strengthening and preserving them; as this would make them dry and harden the better, and prevent their cleaving and cracking. For want of this the outside drying, when the inside does not, the former shrinks faster than the latter; the consequence of which is prejudicial.

BORING, in *Mineralogy*, a method of piercing the earth by a set of scooping irons, made with joints so as to be lengthened at pleasure. The skilful mineralist will be able to guess where a vein of ore may lie, though there are none of the common outward signs of it upon the surface of the earth; and in this case he has recourse to boring; the scooping irons are drawn back at proper times, and the samples of earth and mineral matters they bring up, are examined; and hence it is known whether it will be worth while or not to open a mine in the place. See **COAL**.

BORING, in *Rural Economy*, a practice sometimes employed in order to ascertain the nature of the different strata that lie beneath the surface soil; and also for the purpose of discovering springs, and tapping them, so as to draw off the water that injures the grounds below, or in the neighbourhood. When this last object is in view, boring is generally performed in the bottoms of ditches or drains, previously made in the land, to the depth of several feet. See **DRAINING of Land**.

BORING Augre, an implement employed for the purpose of boring the soil, and letting off water confined beneath it, &c. See **BORE**.

BORING of Water-pipes. The method of boring alder poles for water-pipes is thus: being furnished with poles of a fit size, horses, or tressels are procured of a due height both to lay the poles, and rest the augre on in boring; they

also set up a lath, whereby to turn the lesser ends of the poles, and adapt them to the cavities of the greater ends of others, in order to make the joint shut each pair of poles together. The outer, or concave part, is called the female, and the other, or inner, the male part of the joint. In turning the male part, they make a channel, or small groove in it, at a proper distance from the end; and in the female part, bore a small hole to fit over this channel; they then bore through their poles, sticking up great nails at each end to guide them right; but they commonly bore a pole at both ends; so that if it be crooked one way, they can nevertheless bore it through, and not spoil it. Neve Build. Dict. in voc. Alder.

This operation is now performed with a horse-mill, as at Dorset Stairs for the New River company.

Belidor, in his *Hydraulics*, has described a machine, in which a water-wheel is made use of both to turn the augre, and to bring forward the carriage on which the pipe to be bored rests. This machine (see *Tab. II. Mechanics, fig. 67.*) is put into motion by the water-wheel A, in the axis of which there is a cog-wheel B, that turns the lanterns C and D; the trundles of D turn two small wheels E and F; the first of which is vertical and turns the augre; the other is horizontal and moves the carriage by means of the two arms H and I. H draws the wheel G towards F; and I pushes it in a contrary direction; and these combined actions cause the carriage to advance towards F, and the augre to bore the pipe. The augre being about twelve feet long and proportionally heavy, is supported by the pieces L L; and they are prepared so as to give no obstruction, in the following manner: CC, (*fig. 68.*) are two planks of wood which are fastened to the timber-work of the mill; these encompass another plank, hung by a cord, at the bottom of which are fixed the pieces bb, with joints at e and e, and, that they may not move out of the vertical plane, they are joined by tenons to the plank a, in which they may work freely: on the side of one of these pieces is fixed a spring, g, in order to hinder them from uniting, by forcing them into a mortise, in d; in this situation the two pieces are penetrated with a hole through which the augre is to pass. The cord is fastened to the plank a, as in *fig. 69*, and goes over the two pulleys bb; at the other end of the cord there is hung a weight e, resting on the piece N, which is supported at one end by the piece O, and fixed to the other by a joint to the lever K, which has its centre of motion in the piece of wood H; so that, leaning against the extremity M of the lever, N quits the support O, the weight sinks down, and draws up the piece a; then the sides bb, *fig. 68*, quit the mortise d, and the spring g separates them: and thus the supporter does not in the least hinder the motion of the augre.

Boyle

BOYLE, ROBERT, an eminent philosopher, illustrious by birth, learning, and virtue, was the 7th son of Richard, earl of Cork; and born at Lismore in the county of Cork, February 25th, 1726-7. In his infancy he was committed to the care of a country nurse, with instructions to bring him up hardily, as if he were her own son; and he thus acquired a strong and vigorous constitution, which was afterwards enfeebled by too tender treatment. About the age of 3 years, he lost his mother, whom he mentions with great respect; and whilst he was under the care of his nurse he acquired, by imitating some children of his own age, a habit of stuttering, which was never entirely cured. In his father's house he was taught to write a fair hand, and to speak both French and Latin; and at this early period he manifested a docility and an invariable regard to truth, which very much endeared him to his father, and formed distinguishing features of his character in the progress of his life. In 1635, when he was about eight years of age, he was sent to Eton college, of which sir Henry Wotton was then provost, and placed under the care of Mr. Harrison, to whose attention and judicious mode of instruction he acknowledged himself indebted for those habits of assiduous investigation in which he afterwards excelled. At Eton he was afflicted with an ague, which rendered it advisable to divert his attention from the course of study which he was pursuing, and to allow him to seek that kind of amusement, which the perusal of romances might afford him; but though he was only 10 years old, he was sensible of the injury produced by this kind of desultory reading; and as soon as he regained his health, he sought a remedy for this evil in the severer studies of mathematics and laborious calculations. After having spent between 3 and 4 years at Eton, he was placed under private tuition for the recovery of his knowledge of the Latin language which he had nearly lost; and in 1638 he accompanied his brother Francis on his foreign travels, under the care of Mr. Marcombes. In their route they passed from Dieppe to Rouen, Paris, and Lyons, and at length settled at Geneva, where they were directed to remain and to pursue their studies. The principal objects of Mr. Boyle's attention were mathematics, in the prosecution of which he found great pleasure; but besides these, he employed himself in the study of rhetoric, logic, and political geography, and in acquiring the external accomplishments of fencing, dancing, &c. At this time some incidents happened, which concurred with his naturally serious disposition to direct his thoughts to the subject of religion; and in examining the evidences of the christian revelation, he obtained full satisfaction, notwithstanding the doubts and difficulties which had occasionally perplexed his mind; and was confirmed in his belief of its truth and importance.

Having remained a year and three quarters at Geneva, he left it in September 1641, and traversing various parts of Italy and Lombardy he arrived at Venice; and from Venice he proceeded to Florence, where he spent the winter. During his residence in this city, he acquired a knowledge of the Italian language; and employed a great part of his time in reading modern history; and in acquainting himself with the new discoveries of Galileo, who died in the vicinity of Florence at the period of Mr. Boyle's abode in this city. Towards the end of March, 1642, he commenced his journey to Rome, visiting the most remarkable places in his route thither; and from Rome, where his stay was short, he returned to Florence, and from thence he passed to Leghorn, and afterwards to Genoa. Having travelled through the country of Nice, and crossed the sea to Antibes, he proceeded to Marseilles, where he expected bills of exchange; but, to his great mortification, he found a letter from his father informing him and his brother, that the rebellion had broke out in Ireland, and that it was with considerable difficulty that he had been able to procure for them a remittance of 250l. in order to defray their expences in their return to their own country. But through the negligence of the person, to whom the remittance was entrusted, they received no part of this money, and were, therefore, left in a destitute condition. At Geneva, whither they were enabled to proceed by the assistance of Mr. Marcombes, their governor, they waited two years without receiving any supplies; and by the disposal of some jewels which they took up on his credit, as they proceeded on their journey homeward, their travelling expences were defrayed, and they arrived safe in England about the middle of the year 1644. On their arrival they received the news of their father's death; but Mr. Boyle was amply provided for by the bequest of the manor of Stalbridge in England and other estates in Ireland; and yet on account of the confusion of the times, he was for some months unable to procure any money. However he was relieved on his arrival by his sister the lady Ranelagh; and by her interest, and that of his brother lord Broghill, his English and Irish estates were secured for him. He also obtained leave to go to France; and having settled his accounts with Mr. Marcombes, he soon returned. In March, 1645, he retired to his manor of Stalbridge, and for 5 years devoted himself to various kinds of literary and scientific pursuits in this place; and more particularly to the study of natural philosophy and chemistry. During this period of retirement, when he was about 20 years of age, he commenced that extensive correspondence with the principal persons of his time, which he maintained, with distinguishing reputation to himself and benefit to the world, till near the close of his life. In the list of his first literary friends and correspondents, we may enumerate Mr. Francis Tallents,

afterwards known to the world as the author of the "Chronological Tables;" Mr. Samuel Hartlib, whom he greatly esteemed, and who is mentioned with peculiar commendation by Milton in his "Treatise of Education;" Dr. William Petty; Mr. John Beale, besides many others. At this early age he manifested his zeal for religion, as well as his candour and christian charity, by favouring the designs of Mr. John Drury, for effecting a reconciliation between the Lutherans and Calvinists. He was likewise one of the first members of that learned body, which, after the restoration, was incorporated under the title of the *Royal Society*. Notwithstanding the disease of the stone, with which he was afflicted, and numerous avocations which his various connections imposed upon him, his application to study was assiduous and indefatigable; and before he had attained the age of 20, he had completed three treatises, viz. "Seraphic Love," "Essay on mistaken Modesty," and "the Swearer silenced," or "Free discourse against swearing." Mr. Boyle was distinguished as a promoter of literature and science, by his patronage of others engaged in similar pursuits, as well as by his own labour and writings. Accordingly, in 1651, Dr. Nathaniel Highmore, an eminent physician, dedicated to him his "History of Generation," which was a work at that time much esteemed. Whilst he was unwearied in his chemical and philosophical inquiries and experiments, he was no less attentive to the subject of religion; and with this view he applied to the study of the scriptures in their original languages. About the year 1652 he began his "Essay on Scripture;" and he continued it during frequent interruptions, occasioned by his journeys to Ireland at this period. Ireland, however, where he spent a great part of two years, from 1652 to 1654, did not afford favourable opportunity for prosecuting the researches to which he was devoted; and, therefore, he employed the time of his continuance there principally in anatomical dissections, with the assistance of his friend Doctor, (afterwards sir William) Petty. Upon his return to England in 1654, he settled at Oxford, where he had the advantage of pursuing his experiments, and where he enjoyed the society of many learned friends, who occupied different situations in the university. It was during his residence at Oxford, that he invented, or rather improved, the construction of the air-pump (See AIR-pump); an instrument, by the use of which he was enabled to perform a variety of experiments, relating to the gravity and elasticity, and other qualities of the air, which entitled him to rank amongst the first philosophers of any age. He had at this early period of his scientific career renounced the philosophy of Aristotle, as a system of words instead of things; and attached to the only just and effectual mode of pursuing philosophical researches by experiment, and fearing lest his mind should acquire any improper bias from the ingenuity of the author, he declined the perusal of the works of Des Cartes, whose philosophy was held by many in high estimation. Mr. Boyle did not restrict himself, whilst he continued at Oxford, to the study of philosophy; but he availed himself, in the prosecution of sacred criticism, of the assistance of those great orientalists, Dr. Edward Pococke, Mr. Thomas Hyde, Mr. Samuel Clarke, and Dr. Thomas Barlow, afterwards bishop of Lincoln. His correspondence was also at the same time very extensive; and was carried on for the purpose of the promotion of science with Mr. Henry Oldenburgh, afterwards secretary to the Royal Society, Dr. John Beale, John Evelyn, esq. Dr. John Pett, and Dr. John Wallis, who honoured him with the dedication of his excellent treatise "De Cycloide, et corporibus inde genitis."

In 1659, as soon as he was made acquainted with the distressed circumstances of Dr. Robert Sanderfon, afterwards

bishop of Lincoln, who had been deprived of his preferments on account of his attachment to the royal cause, he settled upon him an annuity of fifty pounds a year; a favour which was respectfully acknowledged by the doctor in his dedication of "Ten lectures on cases of conscience," delivered in Latin in 1647, and printed at Oxford in 1659.

After the restoration in 1660, Mr. Boyle was treated with great respect by the king, and also by the lord-treasurer, lord Southampton, and lord chancellor Clarendon; and by the latter he was urged to enter into holy orders. Having considered the proposal with due attention, his pious scruples determined him to decline the clerical office. In this year he published his "New experiments touching the spring of the air;" which involved him in a controversy with Franciscus Linus and Mr. Thomas Hobbes, and to which he annexed a defence in the edition of 1662; and also his discourse "On seraphic love." Mr. Boyle's reputation had at this time extended itself to foreign countries; so that the grand duke of Tuscany communicated to him by Mr. Southwell, then resident at Florence, his wish to correspond with him on philosophical subjects. In 1661 he published his "Physiological essays, and other tracts;" and soon afterwards his "Sceptical chemist." Other treatises, to which he refers in this publication, and which were in great forwardness, were unfortunately lost at the time of the great fire of London. In 1662, a grant of the forfeited impropriations in Ireland was obtained from the king in his name, but without his knowledge; and they were applied by him to the promotion of religion and learning. He was also appointed governor of the corporation for propagating the gospel in New England; and in this office he was active and successful in restoring an estate, of which they had been deprived by Col. Bedingfield, a papist, although they had given him for it a valuable consideration. In the conduct of the concerns of this institution he was, in other respects, eminently useful. When the Royal Society was incorporated in 1662, Mr. Boyle was appointed one of the council; and as he may justly be regarded as one of the founders of this society, he continued through life one of its most useful and industrious members. In the following year he published his "Considerations on the usefulness of experimental philosophy;" his "Experiments and considerations upon colours," with "Observations on a diamond that shines in the dark;" and "Considerations on the style of the holy scripture," extracted from a larger work, entitled "An essay on scripture," published after his death by Mr. Peter Pett, attorney-general for Ireland. In 1664, Mr. Boyle was elected into the company of royal miners; this new connection, and other engagements of a benevolent and public nature, prevented his publishing any treatises, either on religion or philosophy, in this year. But the year 1665 produced his "Occasional reflections on several subjects;" to which is prefixed, "A discourse concerning the nature and use of such kind of writings." This piece, which had been written by Mr. Boyle in his youth, and at various intervals, was ludicrously attacked by Dr. Swift in his "Pious meditations upon a broomstick, in the style of the honourable Robert Boyle." How far Mr. Boyle possessed in his youth, or acquired in his maturer years, a correct taste and style of writing, particularly in works of imagination, it is now needless to inquire; it is sufficient to observe, that no attack on the part of Dr. Swift can affect the fame of this distinguished person, either as a man or a philosopher. In this year Mr. Boyle, besides some communications to the Royal Society, printed in the *Philosophical Transactions*, published "Experiments and observations relative to an experimental history of cold, with several pieces thereunto an-

nexed;" a work well received at the time, and containing a variety of observations and facts that have been useful to those who, in more modern times, have directed their attention to this interesting subject. Towards the close of this year, his majesty appointed Mr. Boyle provost of Eton college; but he declined accepting this honourable and lucrative office, because he did not wish his studies to be interrupted, and because he thought it more suitable to a person in holy orders.

About this time Mr. Valentine Greatraks, an Irish gentleman of good family and competent fortune, and of a serious disposition inclining to melancholy, persuaded himself that he possessed the power of curing diseases by stroaking. In some cases he succeeded, but in others he failed. His performances, however, were so extraordinary, that they excited very general attention; and an account of them was published, by Mr. Henry Stubbs, in a letter entitled "The miraculous conformist, &c." and addressed to Mr. Boyle. To this letter Mr. Boyle replied; but his answer was not published till eighty years afterwards, in Dr. Birch's account of his life. Nevertheless, the sentiments and reflections contained in it were probably communicated to his friends; and though they were expressed with a caution, candour, and judgment, that did him great honour, they were thought to countenance what some persons deemed a deception, or the mere effects of enthusiasm, and they produced a controversy of some continuance. As far as Mr. Boyle was concerned in this business, it will be sufficient to observe, that, firmly believing the actual exercise of those miraculous powers which attested the truth and divine origin of christianity, and admitting, in consequence of the extent and variety of his researches into the operations of nature, the reality of facts, which he could not immediately reconcile by analogy to the small aggregate of human acquisition, the letter, hastily written by him in reply to Mr. Stubbs, did not at all derogate from his character as a philosopher, or as a man of rational piety. He neither denied nor admitted the existence of the miraculous power ascribed to Mr. Greatraks; but allowing the facts, he proposed a variety of inferences and queries, which demanded discussion; and in the whole of this controversy he conducted himself in such a manner as to avoid personal censure from any of the disputants. See STROAKING.

In 1666 Dr. Wallis addressed to Mr. Boyle "An hypothesis about the flux and reflux of the sea," printed in N° xvi. of the Philosophical Transactions; and Dr. Sydenham dedicated to him his "Methodus curandi febres, propriis observationibus superstructa." His own publications in this year were "Hydrostatical paradoxes;" "The origin of forms and qualities, according to the corpuscular philosophy, illustrated by experiments;" and several papers communicated to the Royal Society, and printed in the Philosophical Transactions of that period. In the dispute that occurred in the establishment of the Royal Society between the adherents to the Aristotelian or old philosophy, and the advocates for the new method of philosophizing by experiments, Mr. Boyle took a decided part with the latter; but without incurring censure or reproach from the most violent of the opposite party. About this time Mr. Boyle removed to London, where he afterwards resided, very much to the advantage of the Royal Society, which he countenanced by his personal presence and philosophical communications; as well as of the cause of science in general.

In 1669, he published his "Continuation of new experiments touching the weight and spring of the air," to which he annexed "A discourse of the atmospheres of consistent bodies;" and also "A discourse of absolute rest in bodies;"

together with other hydrostatical pieces subjoined to his larger works: and in the same year he revised several of his former tracts, which had been translated into Latin for the benefit of foreigners. In the following year appeared his treatise "Of the cosmical qualities of things," containing a variety of interesting facts and observations; and several papers, communicated to the Royal Society. At this time his studies were interrupted by a stroke of the palsy, the effects of which were removed by a strict attention to a proper regimen; so that he soon returned to his labours. In 1671, he published a second volume of "Considerations touching the usefulness of experimental philosophy," and "Tracts of a discovery of the admirable rarefaction of the air, &c.;" and in 1672 appeared his "Essay concerning the origin and virtue of gems," 8vo.; his "Tracts, containing new experiments touching the relation between flame and air, and various other interesting subjects chiefly relating to the statical action of fluids;" and, in the Philosophical Transactions, "Observations on shining flesh," and a paper on the effects of the varying pressure of air. In 1673 he published "Essays on the strange subtlety, great efficacy, and determinate nature, of effluvia;" "Experiments on the weighing and coercion of fire and flame," 8vo.; and "A letter concerning ambergris," communicated to the Royal Society. In 1674 appeared a collection of "Tracts on the saltiness of the sea; on a statical hygroscope; on the natural and preternatural state of bodies, and on the positive or privative nature of cold," 8vo.; "The excellency of theology compared with natural philosophy," 8vo.; "Tracts, containing suspicions about the hidden qualities of the air: animadversions upon Hobbes's problem concerning a vacuum; and a discourse of the cause of attraction by suction," 8vo.; and in this year he communicated to the editor of the Philosophical Transactions, "An account of the two sorts of Helmontian laudanum." In 1675 he published "Some considerations about the reconcileableness of reason and religion," by T. E. a layman; to which is annexed, by the publisher, "A discourse of Mr. Boyle about the possibility of the resurrection," 8vo. T. E. are supposed to be the final letters of his own name, as both these tracts are ascribed to him. In this year he communicated to the Royal Society four papers, which appear in the Transactions: "On the air-bladders of fishes;" "A new essay instrument;" "New experiments touching the spring of the air, &c.;" and "An experimental discourse of quicksilver growing hot with gold." In 1676 he published "Experiments and notes about the mechanical origin of particular qualities," in which he treats of alkalis and acids, heat and cold, tastes, odours, volatility, fixity, corrosive action, precipitation, magnetism, and electricity; and he also communicated to the Royal Society two papers on the configuration of the surfaces of fluids in contact with each other.

Mr. Boyle, having been for several years an active and useful director of the East-India company, wished to avail himself of his office for propagating the gospel in those remote parts to which their commerce extended: and with this view he caused 500 copies of the four gospels and acts of the apostles to be printed at Oxford, in the Malayan tongue, under the direction of Dr. Thomas Hyde, and to be sent abroad at his own expence. For similar purposes of piety and benevolence, he had transmitted, about three years before, several copies of Grotius's treatise "De veritate Christianæ religionis," translated into Arabic by Dr. Edward Pococke, into the Levant.

In 1677 a miscellaneous collection of his works, defective, and badly arranged, was printed in Latin at Geneva.

In the following year he communicated to Mr. Hook a "Short memorial of some observations made upon an artificial substance that shines without any preceding illustration," which was published in that philosopher's "Cutlerian lectures;" this substance was the phosphorus of urine. In this year he also published his "Historical narrative of a degradation of gold made by an anti-elixir," 4to.; and he received a tribute of singular respect, in a letter from the great Newton, laying before him his sentiments concerning an ethereal medium, which he afterwards proposed, in his *Optics*, as the mechanical cause of gravitation. In the year 1680, he published "The aerial noctiluca," 8vo.; and "An account of a new lamp," in Hook's *Philosophical Collections*; and he improved the second edition of his "Sceptical Chymist." Some persons have very unwarrantably asserted, that Mr. Boyle assumed to himself the invention of phosphorus, after having purchased the secret of Kraft. This calumny is refuted by his own narrative, in which he discusses the claims of Brand, Kunckel, and Kraft, and acknowledges the advantage which he derived, in the prosecution of his inquiries, from the information communicated to him by the latter, that the shining substance was obtained from a matter belonging to the human body. From the narrative it appears, that the aerial noctiluca was an aqueous solution, or diffusion of phosphorus, obtained by distillation from putrid urine in an experiment where his retort failed; and which did not prove altogether successful. At the annual election of officers for this year, Mr. Boyle was elected president of the Royal Society; but having objections of delicacy with regard to the official oaths that are required, and for some other reasons, he declined accepting the honour. At this time he contributed very liberally to the publication of Burnet's *History of the Reformation*, as the author acknowledges in his preface to the second volume. It was probably about the beginning of the year 1681, that he exerted himself for promoting the propagation of the gospel among the Indians; as his letter on this subject was a reply to one from Mr. John Elliot, of New England, dated Nov. 4, 1680. From this letter, which is preserved by Dr. Birch, it appears that he was a declared enemy to persecution on account of religious opinions. In this year (1681) he published his "Discourse of things above reason;" and in the following year, "New experiments and observations made upon the icy noctiluca," 8vo.; and also a "Continuation of new experiments physico-mechanical, touching the spring and weight of the air, with a large appendix." It appears that his icy noctiluca was the solid phosphorus, which at first he found some difficulty in making; but from a paper left with the secretary of the Royal Society, to be opened after his death, which was nevertheless communicated to his friend Dr. Beale during his life, we find that he evaporated urine by distillation till it acquired the consistence of syrup, then mixed it with siliceous sand, and distilled by a strong heat into a reservoir containing water. See PHOSPHORUS. In 1683 he wrote a letter, sanctioning and encouraging an undertaking of Mr. Fitzgerald for rendering sea-water fresh; and in the following year, he published his "Natural history of human blood," and his "Experiments and considerations about the porosity of bodies," both in 8vo. From a letter addressed to Mr. Boyle in 1684 by the learned Dr. Cudworth, it appears how highly he appreciated his talents and labours. After recommending a collection of his several treatises, he concludes in these terms: "You have much outdone Sir Francis Bacon in your natural experiments; and you have not insinuated any thing, as he is thought to have done, tending to irreligion, but the contrary." The year 1685 produced his "Short memoirs for

the natural experimental history of mineral waters," and an "Essay on the great effects of even languid and unheeded motion;" to which is annexed an "Experimental discourse of some hitherto little regarded causes of the salubrity and insalubrity of the air," 8vo. In the course of that year appeared in the *Philosophical Transactions*, "An account of a strangely self-moving liquor," which was a compound of oils and bitumens, the ingredients of which, though known to himself, he has not specified: and also a distinct treatise "On the reconcileableness of specific medicines to the corpuscular philosophy, to which is annexed, a discourse about the advantages of simple medicines," 8vo. Besides these philosophical tracts, he presented the world in this year with a theological treatise, entitled, "Of the high veneration man's intellect owes to God, particularly for his wisdom and power," 8vo. The only work that appeared in 1686, was his "Free inquiry into the vulgar and received notion of nature." This treatise was much admired by the advocates for pure religion and sound philosophy; it was translated into Latin, and reprinted in the following year in 12mo. In this year, 1687, he published a work, written in his youth, entitled "The martyrdom of Theodora and Dydimia," and five decades of "Choice remedies," to which when the work was reprinted in 1692, five more were added. In 1688 appeared "A disquisition about the final causes of natural things; wherein it is inquired whether, and if at all, with what caution, a naturalist should admit them; to which was subjoined, by way of appendix, "Some uncommon observations about vitiated light." About the beginning of this year our author found it expedient to apprise the public, by way of preface to his mutilated and unfinished writings, and as a general apology for the state in which they appeared, that some of his papers had been stolen from him, and that others had been destroyed by corrosive liquors. The decay of his health, and the derangement of his affairs in Ireland, obliged him to diminish the number of his communications to the Royal Society, and induced him to resign the office of governor of the corporation for propagating the gospel in New England. From other arrangements with regard to his private affairs, his papers, and the number of visits which he received, it appeared that he was not without apprehensions of an approaching change. The time, however, which he thus reserved to himself, he industriously improved; as he availed himself of it for collecting various elaborate processes in chemistry; which, as we are informed in a letter preserved by Dr. Birch, "he left as a kind of hermetic legacy to the studious disciples of that art." This collection he committed to the care of a friend, enjoining him to impart it to the public faithfully, and without envy, verbatim in his own expressions. This friend is unknown, and the work was never published. From many circumstances, however, we are led to conclude, that Mr. Boyle concurred, with many other ingenious alchymists of the age in which he lived, in believing, what is now rejected as a groundless opinion, the possibility of transmuting the baser metals into gold; and hence, probably, he was led to take pains in procuring, in 1689, the repeal of the statute of the 5th of Henry IV. against the multiplying of gold and silver.

In 1690, he published his "*Medicina hydrostatica, or hydrostatics applied to the materia medica*," 8vo. with the promise of a second volume, which never appeared; and "The christian virtuoso, shewing, that by being addicted to experimental philosophy, a man is rather assisted, than indisposed to be a good christian;" a second part of which was published in an imperfect state, after his death. In 1691, he communicated to M. de la Croze, "An account of some

observations made in the great congregation of waters, by lowering down bottles into the sea 600 feet from the surface," which was printed by that author in the "History of learning." Mr. Boyle's last work, published by himself, was his "Experimenta et observationes physicae;" to which is added "A small collection of strange reports," 8vo.

In July of this year, Mr. Boyle executed his last will, and in the succeeding months his health rapidly declined. On the 23d of December, he lost his sister, lady Ranelagh, to whom he was affectionately attached, and within a week afterwards, viz. on the 30th of December, 1691, he departed this life, in the 65th year of his age, and was interred at the upper end of the south side of the chancel of St. Martin's in the fields, near the remains of his sister, with whom he had lived for the greatest part of 47 years. His funeral sermon was preached by Dr. Burnet, bishop of Salisbury.

Mr. Boyle's posthumous works are as follow: 1. "The general history of the air, designed and begun," 1692, 4to.; 2. "Medicinal experiments, or a collection of choice remedies, for the most part simple, and easily prepared," 1692, 12mo; 3. "General heads for the natural history of a country, great or small, drawn out for the use of travellers and navigators," 1692, 12mo.; 4. "A paper of the honourable Robert Boyle's, deposited with the secretaries of the Royal Society, Oct. 14, 1680, and opened since his death; being an account of his making the phosphorus, &c. Sept. 30, 1680;" 5. "An account of a way of examining waters, as to freshness or saltness;" 6. "A free discourse against customary swearing, and a dissuasive from cursing;" 1695, 8vo. 7. "Medicinal experiments, or a collection of choice remedies, chiefly simple and easily prepared, used in families, and fit for the service of the country people;" the 3d and last volume published from the author's original MSS. A collection of all Mr. Boyle's works was published in 1744, in 6 volumes folio, with a life prefixed, by Dr. Birch; and in 6 vols. 4to. in 1772.

Mr. Boyle, as to his person, was tall and slender, and of a pale and emaciated countenance. His constitution was so delicate, that he regulated his cloathing by a thermometer; and he was occasionally subject to such debility of body, such painful paroxysms of the stone, and such depression of spirits, that we may be well astonished at the number and variety of his scientific and literary performances. However, to the simplicity of his diet, and the strict temperance which he observed, we may reasonably ascribe the degree of health which he enjoyed, and the length to which his life was protracted. His speech was slow and deliberate; and subject to hesitation; in his conversation he was unassuming, never dictating his own opinions, or urging his objections to those of others with confidence, but rather proposing them as topics of inquiry and discussion; and in his manners he was singularly mild and courteous. Although he was a favourite at court, and indulged in free intercourse with three successive sovereigns, viz. Charles II. James II. and William III., he never disguised his sentiments with regard to public men and measures; but he took no active part in the politics of the eventful times in which he lived, preferring the pursuits of philosophy, and the retirement which best suited his infirm frame and religious temper. To the rank of a peerage he never aspired, but refused it whenever it was offered to him. One of the most prominent features of his character, was his sincere and unaffected piety. This was exemplified in all his writings, and in the whole course of his life. Of his firm attachment to Christianity, and of his solicitude for vindicating its truth, and extending the knowledge and influence of it, he ex-

hibited many substantial proofs, both whilst he lived, and at his death. Besides the translation of the gospels and book of acts into the Malayan language, and of Grotius's treatise concerning the truth of the Christian religion into Arabic, which we have already mentioned, and which was conducted at his own expence, he proposed an impression of the New Testament in the Turkish language; and when the Turkey company undertook it, he liberally contributed towards accomplishing it. A translation and edition of the Bible in the Irish language cost him 700l.; and he defrayed a considerable part of the charge attending an impression of the Welsh Bible, and of the Irish Bible for Scotland. He gave, during his life 300l. towards propagating the Christian religion in America; and as soon as he heard that the East India company were projecting a similar design in the East, he sent a donation of 100l. by way of example and encouragement in the prosecution of the scheme. Of the impropriations belonging to his estates he ordered considerable sums to be given to the incumbents in these parishes, and even to the widows of those who had died before this distribution of his bounty. This he did twice during his life to the amount of 600l., and he ordered another distribution as far as his estate would bear, by his will. In other respects, his charities were so numerous and extensive, that they amounted, as bishop Burnet informs us, from his own knowledge, to upwards of 1000l. per annum. The annuity established by his will for providing a series of lectures in defence of Christianity, affords further evidence of the benevolence of his temper, and of his concern for promoting the interests of religion. See Boyle's *Lectures*. His zeal in the cause of religion, though it was

ardent and active, was free from the least tincture of bigotry and intolerance. Whilst he adhered to the established church, he entertained the most undissembled charity towards all who differed from him in opinion: nor did he ever express himself in stronger terms, and with a greater degree of indignation, than when he condemned every kind of severity and persecution in the province of religion. Burnet in his funeral eulogy informs us, that his knowledge comprehended Hebrew and the other Oriental languages, the writings of the most eminent fathers, commentaries on the scriptures, religious controversies, and the whole body of divinity. He represents him as being acquainted with the whole compass of the mathematical sciences, and as well versed even in the most abstruse parts of geometry. Geography, navigation, and books of travels he had recourse to for the relaxation of his mind, and the amusement of his intervals of leisure. Of his knowledge with regard to subjects of natural history, chemistry, and experimental philosophy, his various researches and discoveries, recorded in his numerous publications already recited, afford ample evidence. Mr. Boyle, indeed, possessed in an eminent degree those qualities, which justify his being ranked among the first philosophers of any age or country. He was distinguished by the comprehension of his views, and the extent and variety of his researches, by indefatigable diligence and invincible perseverance in his collection of facts and investigation of their causes, by a total freedom from any preconceived attachment to theories and systems, by candour in discussing the opinions of others, and by fidelity, modesty and perspicuity in the narration of his own performances. Mr. John Hughes might well say of him (*Spectator* N^o 554), after observing that he was born the same year in which lord Bacon died, that he was the person designed by nature to succeed to the labours and inquiries of that extraordinary genius. It would be endless to recount the testimonies in commendation of him, that

might be collected from the writings of the most illustrious foreigners, and of the best judges of his merit in our own country. It will be sufficient to say, that he is uniformly ranked with Bacon and Newton; that his researches and experiments have led the way to many modern discoveries both in philosophy and chemistry: and that his writings will ever be held in high estimation by every friend of science. "They cannot be read," says one of his biogra-

phers, "without improvement; and in these alone, if no life of Boyle had ever been written, the reader would behold a man truly deserving of the affection, the esteem, and the admiration of succeeding ages." Boyle's account of himself, under the name of Philocetus. Birch's life of Boyle, prefixed to his works. Burnet's funeral sermon. Bioz. Brit. Birch's Hist. of the Royal Society. Phil. Trans.

Brass

BRASS, or LATTEN, *Laiton Jaune*, Fr.; *Messing* G. This very important alloy is a mixture of copper and zinc in various and uncertain proportions, so intimately united as to form a homogeneous malleable yellow metal, applicable to a vast variety of purposes in the arts, and capable of being wrought in various ways with the greatest facility.

Mere fusion will scarcely produce a perfect union between copper and zinc; for the latter metal, being highly volatile and combustible, readily takes fire, and burns off at a heat necessary to melt the copper; and hence, when the metals are simply melted together, before an uniform alloy can be obtained, the proportion of zinc is every moment lessening by its volatilization, and would continue to fly off in this manner, by the continuance of the fusion, till at last scarcely any thing but the copper would be left behind. In order, therefore, to combine copper with as much zinc as it can take up, so as to retain its malleability, the very ingenious process of *dry cementation* has been resorted to in the manufacture of brass, which is performed by strongly heating small pieces of copper in close vessels with zinc in the state nearly of vapour, whereby it is thoroughly penetrated with the zinc, and unites with it into a perfect alloy.

Zinc being a volatile metal, it can only be procured from its ores by sublimation; and the process of obtaining it (which will be described at length under that article), is to heat strongly a mixture of the native oxyd with charcoal in a close vessel, with no other exit for the vapour than a tube dipping its further end in water. As soon as the charcoal reduces the oxyd to the metallic state, the zinc rises in vapour, passes through the tube, and is condensed in the water. A similar reduction takes place in brass-making, only, instead of conveying the vapour of the zinc out of the cru-

cible, in which it is formed, copper is inclosed in the same vessel, which being then thoroughly heated, readily absorbs the zinc as soon as reduced to the metallic state, fixes it, contracts a very intimate union with it, and the result is perfect brass.

Brass is made in many countries, but no where more extensively and better than in England, in which both the materials are in great abundance. The ores of zinc are several species of *calamine*, and of *blende* termed by the miners *black jack*, which are found abundantly in Devonshire, Derbyshire, and North Wales, accompanying the lead ores, and in other places. These are chiefly oxyds or carbonated oxyds of zinc, and require a previous calcination before they are fit for brass-making. At Holywell, in Flintshire, the calamine, which is received raw from the mines in the neighbourhood, is first pounded in a stamping mill, and then washed and sifted, in order to separate the lead with which it is largely admixed. It is then calcined on a broad shallow brick hearth, over an oven heated to redness, and frequently stirred for some hours; or, in some places, a conical pile is composed of horizontal layers of calamine alternating with layers of charcoal, and the lowest layer is of wood in large pieces, with intervals left for the draught of air through the centre of the pile, to maintain the combustion thoroughly.

The calamine being fully calcined is then ground in a mill, and mixed at the same time with about a third or fourth part of charcoal, or in some places with pit-coal, which last, however, injures the malleability of the brass. This mixture is then put into large cylindrical crucibles, along with alternate layers of small bits of copper, consisting either of the clippings of copper plates, or of copper shot, made by melting any refuse pieces of this metal, and pouring it into

cold water, which divides it into very small rounded shot-like fragments. Powdered charcoal is put over all, and the crucibles are covered and luted up. The brass furnace has the form of the frustum of a hollow cone, or a cone with the base downwards, and the apex cut off horizontally. At the bottom of the furnace is a circular grate, or perforated iron plate, coated with clay and horse-dung, to defend it from the action of the fire. The crucibles stand upon the circular plate, forming a circular row with one in the middle. The fuel, which in England is coal, is thrown round the crucibles, and is thrown into the furnace at the upper part of it, or the truncated apex of the cone. A perforated cover, made of bricks or clay, and kept together by iron bars, is fitted to this opening. This cover serves as a register to regulate the heat; so that when it is to be increased, the cover is to be partly or entirely removed, and a free draught admitted to the external air, which passes along an underground vault to the ash-hole, through the holes in the circular grate betwixt the crucibles, and through the upper mouth, along with the smoke and flame, into an area, where the workmen stand, which is covered by a large dome with a chimney to conduct the smoke out of doors. To diminish the heat, the register cover is put on the mouth of the furnace, leaving thereby no other exit for the smoke and flame than the holes of the cover. The time requisite for heating the crucibles varies considerably in different works, being determined chiefly by the nature of the calamine or other ore of zinc employed, and also by the size of the crucibles. In the great way, at least ten or twelve hours are required. At Holywell about twenty hours are employed.

During the process, and especially towards the latter end, part of the reduced zinc which escapes, being absorbed by the copper, finds its way in vapour through the crucible lids, and burns around them with the beautiful blue flame and white smoke peculiar to this volatile metal.

The heat required for brass-making is somewhat less than what is necessary to melt copper, for brass is more fusible than copper, and the zinc is able to penetrate copper when kept at a full red heat. When the brass is judged to be made, the heat is increased to fuse the whole down into one mass at the bottom, and the crucibles are then removed, and the melted brass poured out into moulds. At Holywell, six crucibles are used to one furnace; and the quantity of brass procured from them all is sufficient to fill one of them. This makes a single large brass plate, which is manufactured in the same way as copper plate. Or, more accurately, from forty pounds of copper and sixty pounds of calamine, about sixty pounds of brass are obtained, besides that a considerable quantity of zinc burns off in the process above-mentioned.

The above is the usual process of making brass in most parts of England, and is essentially the same wherever this alloy is manufactured, but with some variation as to the choice of ingredients, their proportions, the time of fusion, and other smaller circumstances. In Goslar in Saxony, instead of a native calamine, the *cadmia*, or sublimed oxyd of zinc is used, which is collected in a particular part of the chimnies of the reverberatory furnaces, in which the lead ores and blendes are roasted. The proportions of the ingredients also vary considerably. According to Swedenborg, they are, in Goslar, 30 parts of copper, 40 to 45 of cadmia, and twice the volume of charcoal; in many of the manufactories in France, 35 of copper, 35 of old brass, 40 of calamine, and 20 to 25 of charcoal; in Sweden, 30 of copper, 20 to 30 of old brass, and 46 of calamine, with charcoal sufficient; or 40 of copper, 30 of old brass, and 60 of calamine; in this country, generally about 40 of cop-

per, and 60 of calamine. The product of brass varies also; but it seems to be in few places so great as in some of the works of England, where, as already mentioned, 40 pounds of copper increase to 60 pounds of brass. This superior quantity is ascribed to the smallness to which the copper is previously reduced by pouring it melted into water, which, it seems, is not always practised elsewhere, and probably too to the goodness of the calamine.

At Stolberg, near Aix la Chapelle, where brass is made to a very great extent, the furnaces are cylindrical, and each contains eight crucibles arranged in two tiers of four each. The crucibles are fifteen inches high, twelve inches deep, and eight or nine wide. The proportions are 40 pounds of copper, 65 of calamine, and double its volume of charcoal. After the fire has been kept up for twelve hours, a workman takes off with an iron trowel all the scum and charcoal which swim upon the liquid, and when cooled form a mass called *arkeß*. This, examined by a glass, is found to consist of calamine and copper particles cohering together, but not completely united. The brass resulting from this first process is coarse, brittle, and unequal in texture, and requires a second fusion, before it is fit to be wrought. For this purpose the same crucibles are again employed, and are filled, first with three handfuls of the mixture of calamine and charcoal, over which are put two or three pounds of the impure brass broken in pieces, then more calamine and charcoal, with a piece of the *arkeß*, and over all the calamine and charcoal powder. They are then heated strongly for two hours, after which the brass is fit to be cast into plates.

A single fusion, where the fire is kept up long enough, and the materials are good, is certainly sufficient to make good malleable brass; but it is probable, that the finest sorts undergo a second operation with fresh calamine and charcoal. Some secrecy is, however, observed by those individuals who have the reputation of making the very finest article.

In the laboratory, by way of experiment, brass may be made in a much shorter time by using the same materials, that is to say, copper-shot buried in a mixture of calamine and charcoal, putting the crucible in a wind furnace, and heating slowly for half an hour, till the zinc begins to burn off in blue flame round the cover of the crucible, and then raising the fire, and heating briskly for an hour longer. This process of cementation of copper is also shewn very neatly by a somewhat different management, as given by Cramer. Put the mixture of calamine and charcoal into a crucible; cover it with a thin layer of clay, over which, when dry, lay a thin plate of copper, and cover the whole with fine charcoal powder, and a luted cover to the crucible. Apply heat gradually, and the vapour of the reduced zinc will rise through the floor of clay, will penetrate the red-hot copper above it, and convert it gradually into brass, which, at the end of the operation, will be found lying melted upon the stratum of clay; and the increase of weight, which the copper will be found thus to have gained, will afford a good practical test of the goodness of the calamine, and its fitness for brass-making in the great way.

Brass is wrought into plates by casting and laminating. At Stolberg the plates are first cast into a mould formed of two blocks of hard granite five feet long, three and a half broad, and eight inches thick. These are placed one above the other, and the upper one is raised by a pulley, and smeared with cow-dung previous to casting. To give the plate the requisite thickness, hoops of iron of different dimensions are adapted to the under stone, so as to confine the melted metal, and regulate its thickness. The stones

are gently inclined before the metal is run into them. These plates are afterwards laminated and manufactured in a thousand different ways.

The most important properties of brass, compared with copper, are the following: its colour is much brighter, and more approaching to gold; it is more fusible than copper, as is seen from the circumstance, that less than a copper-melting heat is sufficient for the making of brass; it is less subject to rust, and to be acted on by the vast variety of substances which corrode copper; and lastly, it is equally malleable when cold, and more extensible than either copper or iron; and hence is peculiarly fitted to be made into wire. Brass, however, is only malleable when cold. By hammering, brass is found to become magnetic, perhaps only from the particles of the iron hammer which may have been beaten into its surface; but this makes it necessary to use unhammered brass about compass-needles, and similar magnetic apparatus. The expansion of brass has been very accurately determined, as this metal is most commonly used for mathematical and astronomical instruments, where the utmost precision is required. Mr. Smeaton found that 12 inches in length of cast brass at 32° , expanded by 180° of heat, (or at the boiling point of water,) 225 ten thousandths parts of an inch: brass wire in the same circumstances expanded 232 parts; brass 16 parts, with one of tin, expanded 229 parts. The expansion of hammered copper is only 204 parts, but that of zinc is 353; so that brass holds a middle place in this respect between its two component metals.

The zinc is readily separated from brass by fire. When brass is heated strongly in open vessels to at least a copper-melting heat, the zinc of the brass takes fire, and slowly burns away. If this is continued long enough, little else is left but copper, though still retaining a small portion of zinc, which no further continuance of the heat will entirely separate.

Some kinds of very fine brass, it is said, are not made by cementation in the way already described, but by a more speedy and direct union of copper and zinc, care being taken to prevent the access of air to the materials while in fusion. Very fine brass may also be made in the small way, (and doubtless also in manufacture,) by mixing the oxide of copper and zinc, and reducing them together. This plan is ingenious, and the intimate mixture of the two metals, the great object in brass-making, is probably more accurately obtained in this way than even by the common process of cementation. The following experiment on this plan is given by Sage: Mix together 50 parts of oxide of copper, remaining after the distillation of verdigris (which is a very pure oxide) with 100 parts of lapis calaminaris, 400 parts of black flux, and 30 parts of charcoal powder; melt together, till no longer any blue flame is seen to burn round the top of the crucible. When cold, a fine button of brass is found beneath the scoria, weighing a sixth more than the copper obtainable from the oxide of this metal reduced in the same way, but without the calamine. This brass has a very fine colour, like gold. On this experiment M. Sage observes, that a sixth increase of weight gained by the copper, is the proportion which constitutes the finest brass, and that which copper will always retain, however long kept in fusion, provided the access of air is prevented, as in this case, by the alkaline scoria. When the copper retains a fifth of zinc, the colour is not so fine; and any quantity above a sixth will be expelled by the heat, even when the alloy is covered; and, on coming to the air, the zinc will burn. Hence the cessation of the zinc flame is in this experiment the proof, that the copper now retains no more than a sixth of zinc, and is fine brass.

The analysis of brass is a point of some consequence, and several modes have been proposed, some good, others defective.

Brass may, in some degree, be analysed by strongly heating in an open vessel, as above mentioned. The zinc then burns off, and when no more flame is given out, the copper is supposed to be pure. But Dizé has found that this mode is very uncertain; so that no two assays of the same sample correspond, for it is not easy to tell when all the zinc is burnt off that can thus be volatilized; and the increase of weight, caused by the oxidation of part of the copper, throws a further uncertainty on this method.

Neither will a simple solution of brass in the sulphuric, or any other acid, and crystallization, answer the purpose; for, though much of the crystallized sulphate of copper may readily be picked out from the sulphate of zinc, the perfect separation of the two kinds of crystals is impracticable, and at last one species becomes mixed with a portion of the other, even in the respective crystals.

M. Dizé proposes the following methods:

1. Dissolve the brass in nitric acid, which takes up the copper and zinc, and leaves any tin with which it is often alloyed. Decompose the clear nitrated solution by pot-ash, redissolve the precipitate in sulphuric acid, and add a piece of clean bright iron to the solution, previously diluted with six parts of water. The copper is thus precipitated in the metallic state, and the solution now holds sulphate of iron, and sulphate of zinc. Thence M. Dizé proposes to separate by gallic acid, which slowly precipitates the iron, and leaves the zinc. Lastly, the sulphate of zinc may be decomposed by a carbonated alkali, and the quantity of zinc in the carbonate may be estimated according to proportions, which will be presently mentioned.

This method is useful, but the separation of the iron from the zinc by the gallic acid, is excessively tedious. Sulphuretted hydrogen gas would be much shorter, and to be preferred.

2. Dissolve brass in nitric acid, dilute with six parts of pure water, and immerse in the solution a cylinder of bright clean lead. The copper speedily separates in the metallic state round the lead, which last takes its place in the solution. As this advances, the liquor loses its blue colour; and when all the copper is separated, it becomes slightly yellow. To determine, however, whether all the copper is separated, add a fresh clean piece of lead, and boil the solution for some time. This now contains nitrate of lead, and nitrate of zinc. Sulphuric acid will precipitate thence the lead in the form of an insoluble sulphate, and the nitrated zinc may then be decomposed by a carbonated alkali. On this precipitation, however, there are some observations to be made. Copper, when dissolving in nitric acid, absorbs nearly $\frac{1}{100}$ of its weight of oxygen; but lead, under the same circumstances, absorbs only $\frac{1}{1000}$. Hence (as Vauquelin remarks on this subject of the analysis of brass) 100 parts of copper dissolved in nitric acid would require, for their dioxygenation, (which takes place whenever one metallic oxide in solution is precipitated in a metallic form by another metal immersed in it,) full 250 parts of lead, which last is of course oxidated in proportion as the copper precipitates in the metallic form. But this large quantity of oxide of lead cannot be held in solution by the nitric acid, except this is largely in excess; and this explains why, as M. Dizé has observed, a portion of oxide of lead is apt to form at the latter end of the process, and to mix with the copper, so as to require a subsequent operation to get the copper free from it. Nor will an excess of acid ensure the purity of the precipitated copper; for M. Vauquelin finds that

if 50 grains of pure copper are dissolved in nitric acid to excess, and then precipitated by metallic lead, of which about 220 grains are requisite, the cupreous precipitate weighs 138 grains instead of the original 50 grains, and therefore is not pure copper, but an alloy of this metal, with a very large proportion of lead. This method, therefore, of analysing brass is highly erroneous, unless the supposed copper precipitate be separately treated, in order to free it from the large proportion of lead with which it must be alloyed.

The following methods are given by Vauquelin :

3. Dissolve a given quantity of brass in nitric acid, put it in a well-closed bottle, and add caustic pot-ash to excess, so that there shall be a sensible alkaline taste in the liquor ; shake the mixture well, and keep it a short time in digestion. By this simple process the oxyd of copper is precipitated by the alkali, but the oxyd of zinc is re-dissolved in it ; and if the liquor be now filtered, the alkaline solution of zinc passes through clear, and the oxyd of copper is left behind. This oxyd is brown, and nearly metallic in appearance. When thoroughly washed, and gently dried, it contains 65 per cent. of metallic copper. If one is assured by a previous assay, that the brass only contained copper and zinc, when the quantity of copper is thus obtained, that of the zinc may be inferred from the difference between the copper, and the weight of the brass employed ; or else the alkaline solution of zinc may be supersaturated with sulphuric acid, so as at first to precipitate, and afterwards to re-dissolve the zinc, after which this metal may be precipitated as a carbonat, by adding carbonat of pot-ash or soda. A very trifling quantity of copper passes into the alkaline solution of the zinc, occasioned by a small portion of ammonia formed by the nitrated metals when the caustic alkali is added, which takes up this atom of copper. If necessary, the copper might be again precipitated by heating the alkaline solution, so as to expel the ammoniac ; but not to boiling, otherwise some of the zinc would separate from the alkali, and cause a greater error.

4. Dissolve brass in sulphuric acid, dilute with 20 times as much water, and immerse a stick of zinc exactly weighed. The copper soon precipitates completely in the metallic state, which is to be well washed and weighed. The solution now contains only the zinc of the brass, and the zinc dissolved out of the stick of metal immersed. By weighing the undissolved stick of zinc, and precipitating the whole by carbonat of pot-ash or soda, an easy calculation will give the portion of zinc belonging to the brass : or, more simply, this may be inferred from the copper obtained, and the quantity of brass originally employed.

It only remains, on the subject of analysis, to give the metallic contents of carbonat of zinc. Dizé dissolved 100 parts of zinc in nitric acid, precipitated it by carbonated soda, and this product, well washed and dried, now weighed 180 parts. Hence 100 parts of carbonat of zinc thus obtained,

contain 55.5 of metallic zinc.

On the other hand, Vauquelin found that carbonat of zinc obtained from the sulphat by carbonated pot-ash, well washed and calcined in a crucible to expel all the carbonic acid, contained 69 per cent. of metallic zinc. Hence the carbonat obtained by Dizé, it is obvious, must only have been dried at a low temperature, probably that of boiling water ; and from either of the above data the quantity of zinc may be estimated : or else the carbonat or oxyd may be mixed with charcoal, and strongly heated in an earthen retort, without the access of external air, by which the zinc will be reduced, and will distil over, and condense in the cool neck of the retort in the metallic state.

Analysis shews a vast variety in the proportions of the different species of brass used in commerce ; nor is it easy to determine whether the perfection of this alloy depends on any certain proportion of the two metals, or the mode of manufacture. In general, the extremes of the highest and lowest proportion of zinc are from 12 to 25 parts in the hundred. Even with so great a quantity of zinc as 25 per cent., the ductility of brass is not injured, provided it be manufactured with care, though zinc itself is scarcely malleable. In proof of this, Dizé analysed a specimen of a remarkably fine brass, which is made at Geneva for escapement wheels, and other nicer parts of watch-making. This metal unites great beauty of colour to a high degree of ductility ; and the bars that are perfect fetch a very high price with the watch-makers of this town, so celebrated for this delicate manufacture. This brass was found to consist of 75 of copper, and 25 of zinc. Probably, too, the copper was Swedish, or of some other very superior kind. The common brass of Paris appears to contain no more than about 13 per cent. of zinc. The English, probably, contains more zinc.

The use of brass is of very considerable antiquity ; but from the inaccuracy of the ancient descriptions, and their ignorance of the true nature of zinc and its ores, much uncertainty prevails on this subject. Most of the genuine relics of antiquity of this kind are composed of various mixtures of brass, with tin and other metals, and are rather to be termed *bronzes*. For this and the other yellow alloys of copper, see COPPER.

Keir, in a note to the article brass in Macquer's dictionary ; Watson's Essays ; Sage in J. Phys. vol. xxxviii. ; Dizé in ditto, vol. xlviii. ; Repertory, vol. xiv. ; Vauquelin in An. Ch. vol. xxviii. ; Encycl. Meth. ; Original, &c.

BRASS, in *Antiquity*. See *Æs*.

BRASS, in a more extensive sense, includes copper, and all the mixtures or alloys of copper with other minerals. In which sense, brass amounts nearly to the same with the Roman *æs*, and the French *airain*.

BRASS-lumps, or BRASSES, in *Mineralogy*, a common name among the colliers for the masses of pyrites that are found to accompany, more or less, the different kinds of coal.

Brewing

BREWING, *Brassage de la bière*, Fr. *Das Brauen*, Germ. The art of brewing, or of preparing a vinous fermented liquor from the farinaceous seeds, is of very high antiquity. The ancient Egyptians, from the soil and climate of their country not being favourable to the culture of the vine, were induced to seek a substitute in barley, from which, in all probability, by the process of malting, they knew how to procure a fermented liquor. The town of Pelusium, situated on one of the mouths of the Nile, was

particularly celebrated for its manufactories of malt liquor, of which there were two kinds; one called *Carmi* was sweet, and appears to have resembled our sweet and glutinous ales, the other named *Zithum*, seems to have been analogous to modern beer. The Germans, from the testimony of Tacitus, were capable of preparing a liquor similar to wine (*quandam vini speciem*) from barley, by fermentation. Julian, Strabo, and Polybius, show, that the same art

was

was known to the Spaniards, the Gauls, and the inhabitants of the British islands, and the north of Europe. All the ancient malt liquors, however, seem to have been made entirely of barley, or some other farinaceous grain, and therefore were not generally calculated for long keeping, as this quality depends considerably, though not entirely, on the bitter extract of hops, or other vegetables, with which the liquor is mingled.

Modern malt liquor is essentially composed of water, of the soluble parts of malt and hops, and of yeast.

For a particular account of the preparation of MALT, we refer our readers to that article. It will be sufficient for our present purpose, to mention, that barley consists of fecula or starch, albumen, and a little gluten; and, that by the process of germination or malting, the starch is converted into saccharine mucilage. If each grain of barley was perfectly malted, the whole of its starch would be changed into sugar; this, however, is never the case: the soluble contents, therefore, of such malt as the brewers make use of, arranged in the order of their respective proportions, are saccharine mucilage, starch, albumen, and gluten, of which only the first is absolutely necessary for the production of a vinous liquor. Three or four different kinds of malt are distinguished by the brewer by their colours, which depend on the degree of heat that was used in the drying. Malt that has been dried by a very gentle heat scarcely differs in its colour from barley; if exposed to a somewhat higher temperature, it acquires a light amber-yellow hue; and by successive increments of heat, the colour becomes deeper and deeper, till, at length, it is black. The change of colour is owing to the grain being partially charred or decomposed; and in proportion to the extent to which this alteration is allowed to proceed, will the produce of sugar, that is of fermentable matter, be diminished. The principal advantage of high-dried malt over the paler kind, is the deep yellowish brown tinge which it gives to the liquor: but this colour may be communicated much more economically by burnt sugar. The malt, whether pale or high-dried, must be bruised between rollers, or coarsely ground in a mill before it is used, and it is found by experience, that malt which has lain to cool for some weeks is, in many respects, preferable to that which is used as it comes hot from the mill. The first step in the process of brewing, is

§ 1. *Mashing.*

This is performed in the *mash-tun*, which is a circular wooden vessel, shallow in proportion to its extent, and furnished with a false bottom, pierced with small holes, fixed a few inches above the real bottom: when it is small, it ought to have a moveable wooden cover. There are two side-openings in the interval between the real and false bottom; to one is fixed a pipe for the purpose of conveying water into the tun; the other is fitted with a spigot for the purpose of drawing the liquor out of the tun. The brewing commences by throwing the grist or bruised malt evenly over the false bottom of the mash-tun, and then, by means of the side pipe, letting in from the upper copper the proper quantity of hot water. The water first fills the interval between the two bottoms, then forcing its way through the holes in the false bottom, it soaks into the grist, which, at first floating on the surface of the water, is thus raised off the bottom on which it was spread. When the whole of the water is let in, the process of mashing, properly so called, begins. The object in mashing is to effect a perfect mixture of the malt with the water, in order that all the soluble parts may be extracted by this fluid: for this purpose, the grist is first incorporated with the water by

means of iron rakes, and then the mass is beaten and agitated, and still further mixed by long flat wooden poles, resembling *oars*, which indeed is the name by which they are technically known. In some of the large porter breweries, the extent of the tun is so great, that the process of mashing cannot be adequately performed by human labour, and recourse is had to a very simple and effectual instrument for this purpose. A very strong iron screw, of the same height as the mash-tun, is fixed in the centre of this vessel, from which proceed two great arms or radii, also of iron, and beset with vertical iron teeth a few inches asunder, in the manner of a double comb: by means of a steam engine, or any other moving power, the iron arms which at first rest on the false bottom, are made slowly to revolve upon the central screw, in consequence of which, in proportion as they revolve, they also ascend through the contents of the tun to the surface; then, inverting the circular motion, they descend again in the course of a few revolutions to the bottom. These alternate motions are continued till the grist and water are thoroughly incorporated. When the mashing is completed, the tun is covered in to prevent the escape of the heat, and the whole is suffered to remain still, in order that the insoluble parts may separate from the liquor: the side spigot is then withdrawn, and the clear wort is allowed to run off, slowly at first, but more rapidly as it becomes fine, into the lower or boiling copper.

The operation of mashing, as it is the first in order, is the most important; and all the succeeding ones are modified according to the circumstances, under which this primary one is effected. The principal thing to be attended to, is the temperature of the mash, which depends, partly on the heat of the water, and partly on the state of the malt. If any quantity of barley is mingled with twice its bulk of water, the temperature of the mass will be very nearly that of the mean temperature of the ingredients. If the palest malt is subjected to the same experiment, the temperature will be somewhat greater than that of the mean heat. This excess is found to increase very rapidly, in proportion to the colour or dryness of the malt employed; so that when one part of the highest dried malt is mixed with two parts of warm water, the temperature will be no less than 40° Fah. above the mean. In calculating, therefore, the heat of the mash, it is necessary to take into consideration, both the dryness of the malt, and the proportion which it contains of unmalted, or imperfectly malted barley. The object in mashing is to extract from the malt, as much as possible of the saccharine mucilage; but this is so intimately combined with the other parts of the grain, that the range of temperature which can be employed for this purpose, is very confined. If the water was let upon the grist boiling hot, the starch which it contains would not only be dissolved, but converted into a gelatinous substance, in which all the other parts of the malt, and most of the water, would be entangled, beyond the possibility of recovery by any after-process; and great loss is perpetually sustained by inattentive brewers, from this very circumstance. The most eligible temperature upon the whole for mashing, appears to be about 185° to 190° of Fahrenheit: the heat of the water, therefore, for the first mashing, must be somewhat below this temperature, and the lower in proportion to the dark colour of the malt made use of. Thus, for pale malt, the water of the mash may be at 180° and upwards; but for high-dried brown malt, it ought not much to exceed 170°. The wort of the first mashing is always by much the richest in saccharine matter; but to exhaust the malt, a second and third mashing is required; and as no heat is generated, except in the first mashing, the water in the succeeding ones may

may be safely raised to nearly 190°. The proportion of wort to be obtained from each bushel of malt, depends entirely on the proposed strength of the liquor. For sound small beer, 30 gallons of wort may be taken from each bushel of malt; but for the strongest ale, only the produce of the first mashing, or about 6½ gallons per bushel, is employed. But whatever be the proportion of wort required, it must be held in mind, that every bushel of well made malt will absorb, and retain 3½ gallons of water, and therefore the water made use of must exceed the wort required, in the same proportion.

It is of great importance to the brewer, to ascertain the strength of his worts, or their richness in saccharine matter; this may be done, partly by the taste, but more accurately by an instrument called a *Saccharometer*, which in fact is only a hydrometer, the scale of which is adapted to the various densities of wort. The name *Saccharometer*, however, is an improper one, as it is apt to mislead the brewer: this instrument shews merely the specific gravity of the liquor, and this depends, not only upon the sugar, but the starch, and every other part of the malt which is soluble in water. But the relative proportions of these substances are, in all likelihood, very various in different parcels of malt; whence arises a serious objection to much dependence on the *saccharometer*.

§ 2. *Boiling and hopping.*

If only one kind of liquor (whether ale or beer) is to be made, the produce of the three mashings is to be mixed together: but, if both ale and beer are required, the wort of the first, or of the first and second mashings, is appropriated to the ale, and the remainder is set aside for the beer. All the wort destined for the same liquor, after it has run from the mash-tun, is transferred to the large lower copper, and mixed while it is heating with the required proportion of hops. The stronger the wort is, the larger proportion of hops does it demand: and this is calculated in two ways, either according to the quantity of malt employed, or the richness of the wort. Where the former basis of calculation is referred to, the quantity of hops, especially in private families, where economy is not so strictly attended to as in large establishments, is one pound of hops to a bushel of malt, whether the wort is intended for the strongest ale, or the weakest small beer. In public breweries, the proportion of hops is considerably smaller, and is regulated, not merely by the quantity of malt, but the richness of the wort. For strong ales, the common proportion is about 1 lb. of hops to 1. 3 bushel of malt; for beer, the quantity is lowered to 1 lb. of hops to 1. 7 bushel of malt. When both ale and beer are brewed from the same malt, the usual practice is to put the *whole* quantity of hops in the ale-wort; and after they have been boiled a sufficient time in this, to transfer them to the beer-wort, in order to be exhausted by a second boiling.

When the hops are mixed with the wort in the copper, the liquor is brought to boil; and the best practice is to keep it boiling as fast as possible, till, upon taking a little of the liquor out, it is found to be full of minute flakes, like curdled soap. These flakes consist of the gluten and starch of the malt separated from their former solution in the wort, by the joint action, in all probability, of the heat, and the bitter extract of the hops. For the ascertainment of this important question, no regular experiments, however, have been as yet instituted.

The boiling copper is in most breweries uncovered, but in some it is fitted with a steam-tight cover, from the centre of which passes a cylindrical pipe, that terminates by several recurved branches in the upper or mashing copper: the steam,

therefore, produced by the boiling, instead of being wasted, is let into the cold water of the upper copper, and thus raises it very nearly to the temperature required for mashing, besides impregnating it very sensibly with the essential oil of the hops, in which the whole of the flavour resides, and which would otherwise be discharged into the air, and thus be lost.

§ 3. *Cooling.*

When the liquor is sufficiently boiled, it is discharged into a number of shallow tubs called coolers, where it remains exposed to a free draft of air, till it has deposited the hop-seeds and coagulated flakes with which it was charged, and is become sufficiently cool to be submitted to the next process, which is that of fermentation. It is necessary that the process of cooling should be carried on as expeditiously as possible, particularly in hot weather; for unfermented wort, by exposure to a hot close air for a few hours, is very liable to contract a nauseous smell and taste, when it is said technically to be *foxed*, in consequence of small spots of white mould forming on its surface. Liquor made from pale malt, and which is intended for immediate drinking, need not be cooled lower than 75° or 80°, and in consequence may be made all the year through, except perhaps during the very hottest season; but beer from brown malt, especially if intended for long keeping, requires to be cooled to 65° or 70°, and therefore cannot possibly be made except in cool weather; hence it is that the months of March and October have always been reckoned peculiarly favourable to the manufacture of the best malt liquor.

§ 4. *Tunning and barrelling.*

From the coolers the liquor is transferred into the fermenting or working tun, which is a large cubical wooden vessel capable of being closed at pleasure. As soon as the wort is let in, it is well mixed with yeast, in the proportion of about one gallon to four barrels, and in about five hours afterwards the fermentation commences. The signs of fermentation are muddiness of the liquor, the formation of froth or yeast on the surface, and a copious disengagement of carbonic acid. In the first stage of fermentation, on taking some of the yeast in a bowl it soon falls down into a liquid; but when the fermentation is sufficiently established to allow of barrelling, the yeast has a certain degree of toughness, and will remain a long time without falling in. When the wort is let down hot into the working tun, the fermentation is conducted with the tun closed, and proceeds rapidly, so that in about 18 or 20 hours it is fit to be cleaved or put into the barrels; but when the wort is let down at 65° it requires 48 hours for the first fermentation, and is peculiarly liable to be affected by a considerable change of weather.

Although, in common practice, the coagulated fecula and gluten are deposited and left in the coolers, yet, skilful brewers mix them again with the wort by agitation, and ferment the liquor in this state. Fermentation is considerably retarded by this practice; but, in return, the liquor is much clearer and more completely fermented, as is obvious from the remarkable diminution of specific gravity which it undergoes.

The last process is transferring the liquor from the working tun to the barrels, when the fermentation is completed. During a few days, a copious discharge of yeast takes place from the bung hole, and the barrels must be carefully filled up every day with fresh liquor: this discharge gradually becomes less, and in about a week ceases; at which time the bung-hole is closed up and the liquor is fit for use, after standing from a fortnight to three months according to its strength, and the temperature at which it has been fermented.

BREWING, among *Distillers*, denotes the method of extracting the more soluble parts of vegetables with hot water, and thus procuring a solution or decoction fitted for vinous fermentation.

In which sense brewing is a necessary step towards distillation.

A fermentable solution, fit for yielding a spirit or brandy, is obtainable from any vegetable, under proper management; but the more readily and perfectly the subject dissolves, the better it is disposed for fermentation, and the production of brandies. Thus sugar, honey, treacle, manna, and other inspissated vegetable juices, which totally unite with water, into a clear and uniform solution, are more immediate, more perfect, and better adapted subjects of fermentation than roots, fruits, or herbs, in substance, the grains, or even malt itself; all which dissolve but very imperfectly in hot water.

Yet malt, for its cheapness, is generally preferred in Eng-

land, and brewed for this purpose, much after the common manner of brewing for beer; only the worst malt will serve for distillation; and the tincture, without the addition of hops, and the trouble of boiling, is here directly cooled and fermented.

The grain intended for brewing is previously malted, to prepare it for dissolving more easily and copiously in the water, so as to afford a richer tincture or solution, which, after due fermentation, will yield about one half more of proof spirit than the tincture of an equal weight of unmalted corn.

Brewing is also used, in an ill sense, for the counterfeiting and compounding especially of wines. Vintners and wine-coopers are suspected of brewing wines, or mixing divers inferior sorts, to imitate some better kind. The necessity of accommodating their liquors to the palates of their guests, is another cause of brewing; insomuch that some have confessed they commonly draw out of two or three casks for every pint.

Brick

BRICK, a kind of factitious stone, composed of an argillaceous earth, tempered and formed in moulds, dried in the sun, or burnt in kilns.

The use of bricks is of the highest antiquity. The earliest buildings of Asia were of bricks, dried in the sun, and cemented with bitumen. In this manner, we learn from the historical books of the Old Testament, Nineveh was built by Nimrod; and the famous walls of Babylon, reckoned by the Greeks among the wonders of the world, were of the same materials.

Unburnt bricks were used in Egypt: the making of them was one of the oppressions to which the Israelites were subjected during their servitude in that country. The antique edifices which at present exist in Egypt are principally of stone: however, Pococke describes a pyramid of unburnt brick, called "Kloub-el-Menshie" (the bricks of Menshie), from a village near, called Menshie-Dashour. It was doubtless built near the plain, on account of the bricks, which seem to be made of the earth brought by the Nile, being of a black sandy earth, with some pebbles and shells in it. It is mixed up with chopped straw, in order to bind the clay together; as they now make unburnt bricks in Egypt, and many other eastern parts, which they use very much in their building. I found some of these bricks $13\frac{1}{2}$ inches long, $6\frac{1}{2}$ inches broad, and 4 inches thick; and others 15 inches long, 7 inches broad, and $4\frac{1}{2}$ inches thick. I observed on the north side the bricks were laid lengthways from north to south, but not every where in that direction; however, I particularly took notice that they were not laid so as to bind one another. It is much crumbled and ruined, but as it is I measured it, and found it to be 157 feet on the north side, and 210 feet on the west side; it is 150 feet high. By what I could judge, from the present slope of it, I concluded that it was built with five degrees, like the pyramid of Saccara, each being about 10 feet broad and 30 deep, so

that the ascent to it is easy, as the bricks are crumbled away."

The Greeks and Romans also used this material, both sun-dried and burnt. Vitruvius instances several celebrated buildings, as the walls of Athens; the cells of the temples of Jupiter and Hercules, which were of brick, the surrounding columns and entablature being of stone; the ancient walls of Arezzo in Italy; the house built by the Attalic kings at Tralles, which was always given for the habitation of those who bore the office of priests in that city. The paintings which were brought from Lacedæmon to ornament the Comitium, in the edileship of Varro and Murena, were cut from walls of brick; the house of Cræsus at Sardis; and the celebrated tomb of Mausolus, in which, though the ornaments were all of Proconnesian marble, the walls were built of brick, and (says Vitruvius) remain to this time exceedingly substantial, and the incrustation appears as polished and shining as glass.

The following directions for making unburnt bricks are given by Vitruvius. They should not be made of sandy, stony, or gravelly loam, for such kind of earth renders them heavy; and upon being wetted with rain after being laid in the wall, they swell and dissolve, and the straw which is put in them does not adhere on account of their roughness: the earth of which they are formed should be light chalky white or red. They should be made in spring or autumn, as being the best time for drying; for the intense heat of summer parches the outside before the inside is dry, which afterwards drying in the building, causes them to shrink and break. They are best when made two years before they are used, as they cannot be sufficiently dry in less time. If they are used when newly made and moist, the plaster work which is laid on them remaining firm and stiff, and they shrinking, and consequently not preserving the same height with the incrustation, it is by such contraction, loosened and

separated. At Utica, therefore, the laws allow no bricks to be used before they have lain to dry five years.

Vitruvius proceeds to describe the different kinds of bricks, which were of three sizes; the first, called *didoron*, were in general use among the Romans; they were a foot long, and half a foot broad. The other two sorts were used by the Greeks; one called *tetradoron*, which were on every side four palms, or one foot; the other *pentadoron*, five palms, or fifteen inches every way: the first were used in private, and the latter in public edifices. They had also half bricks of each sort; and in building, the whole bricks were laid in one course, and the half in the next.

At Pitane in Asia, at Calentum in Spain, and at Martulla, they had bricks so light as to swim on water, the earth of which they were made being of the nature of pumice stone.

When Vitruvius mentions bricks, it appears that he means sun-dried bricks; for he observes, that bricks could not be used by the Romans within the city; as to save room in so crowded a town, the laws did not permit any walls in public places to be made thicker than one foot and a half, while brick walls of that thickness would not support more than one story. Accordingly, the walls were built with hewn stone, *testaceous substances* (*structuris testaceis*), or rubble. That these testaceous substances were tiles, is evident, for he observes, that it could not be known at first whether they were of good loam and well burnt, but that they should be laid in a roof during a winter and summer before they were used in a wall.

Augustus boasted that he had found Rome of brick, and left it of marble. It could be only sun-dried bricks that he referred to, for baked bricks were used in the most sumptuous edifices: the temple of Peace, the Pantheon, and all the *Thermæ* were of this material.

Whatever may be the precise time of the introduction of baked bricks in the edifices of Rome, they appear to have been always square. M. Quatremere de Quincy, in the *Encyclopédie Methodique*, observes, that in his researches among the antique buildings of Rome, he has found bricks of three sizes. The least were $7\frac{1}{2}$ inches square, and $1\frac{1}{2}$ thick; the medium ones $16\frac{1}{2}$ inches square, and from 18 to 20 lines in thickness; and the larger ones 22 inches square, by 21 or 22 lines thick. The smaller bricks were employed to face walls of rubble work; and to make a better bond with the wall, they were cut diagonally into two triangles, the longer side was placed on the outside, and the point towards the interior of the work. To tie more effectually the facing with the rubble, they placed at every four feet in height one or two courses of the large square bricks. The large bricks were also used in the arches of openings or discharge, which were necessary in the building.

No long bricks, such as are used at present, are found in antique constructions.

In modern times, bricks have been used in all countries. Chardin thus describes the manufacture of bricks in Persia. The material of Persian buildings is brick, either dried in the sun or burnt in the fire. The tiles or bricks of earth are made in thin wooden moulds, of 8 inches long, 6 wide, and $2\frac{1}{2}$ inches thick. The labourers temper with their feet the earth, which is generally mixed with straw cut very small, to give it more consistence, and that the bricks may last longer and not break. They pass the hands over the bricks to smooth them, after having dipped them in a vessel of water mixed with straw, still finer than was at first used. Then taking off the mould they leave the bricks to dry for two or three hours, after which they are ranged over one another, where they remain till the drying is completed.

The baked bricks are made of two parts of earth and one of cinders, well tempered together, in moulds larger than for the others. They leave them to dry in the sun for several days, then place them in a large furnace, ranged one over the other, at some distance, which they fill with plaster. They close the furnace and light the fire, which is kept up for three days and nights.

Bricks have several advantages over stone as building materials. From their porous structure they unite better with the cement used: they are lighter than stone, and not subject to attract damps and moisture.

The earth proper for the manufacture of bricks is a clayey loam, neither abounding too much in sand, which renders the ware heavy and brittle, nor yet with too large a proportion of argillaceous matter, which causes it to shrink and crack in drying.

The general process of the manufacture is as follows: The earth should be dug in the autumn; it should lie during the whole of the winter exposed to the frost, as the action of the air, in penetrating and dividing the particles of the earth, facilitates the subsequent operations of mixing and tempering. During this time the earth should be repeatedly turned and worked with the spade. In the spring the clay is broken in pieces, and thrown into shallow pits, where it is watered and suffered to remain soaking for several days. The next step is that of tempering the clay, which is generally performed by the treading of men or oxen. In the neighbourhood of London, however, this operation is performed by means of a horse-mill. The tempering of the clay is the most laborious part of the process, and that on which the perfection of the manufacture essentially depends. It is to neglect in this part, that we are chiefly to attribute the bad quality of modern bricks, in comparison with the ancient. All the stones should be removed, and the clay brought to a perfectly homogeneous paste, using the least possible quantity of water.

The following experiment, made by M. Gallon, merits attention. He took a certain quantity of the earth, prepared for the making of bricks; he let it remain for seven hours, then caused it to be moistened and beaten during the space of thirty minutes: the next morning the same operation was repeated, and the earth was beaten for thirty minutes; in the afternoon it was again beaten for fifteen minutes. Thus this earth had only been worked for an hour and a quarter longer than usual, but at three different times. The material had acquired a greater density by this preparation; for a brick made with this earth weighed five pounds eleven ounces, while another brick, made in the same mould, of the earth that had not received this preparation, weighed only five pounds seven ounces. Then having dried these bricks in the air, during the space of thirteen days, and having burnt them along with others, without any particular precautions, they were examined when taken from the kiln, and it was found that the bricks made of the earth which had been the most worked still weighed four ounces more than the others, each having lost five ounces by the evaporation of the moisture. But their strength was very different; for on placing them with the centre on a sharp edge, and loading the two ends, the bricks formed with the well-tempered earth, were broken with a weight at each end of 65 pounds or 130 pounds in all, while the others were broken with 35 pounds at each end, or 70 pounds in the whole.

The earth, being sufficiently prepared in the pits, is brought to the bench of the moulder, who works the clay into the brick-moulds, and strikes off the superfluous earth. The bricks are delivered from the mould and ranged on the ground; and when they have acquired a sufficient hardness

to admit of handling, they are dressed with a knife, and flaked or built up in long dwarf walls, and thatched over, where they remain to dry.

The burning of bricks, which is the next operation, is performed either in a kiln or a clamp. In the former, the bricks being set in, and the kiln covered with pieces of brick, they put in wood to dry them with a gentle fire; and this they continue till they are pretty dry, which is known by the smoke turning from a whitish to a thin black smoke. They then cease to put in wood, and proceed to burn with brush, furze, straw, brake, or fern faggots, having first closed up the mouth of the kiln with a thin log (pieces of brick piled upon one another and closed with wet brick earth instead of mortar), then they continue to put in more faggots till the kiln and its arches look white, and the fire appears at the top, upon which they slacken the fire for an hour, and let all cool by degrees. Thus they continue alternately heating and slackening, till the ware be thoroughly burnt, which is usually effected in 48 hours.

About London they burn in clamps, built of the bricks themselves, after the manner of arches in kilns, with a vacancy between each brick's breadth, for the fire to play through; but with this difference, that, instead of arching, they gather the flues over by making the bricks project over one another. The place for the fuel is carried up straight on both sides till about three feet high; they then nearly fill it with wood, and over that lay a stratum of sea coal, and then overspan the arch; sea-coal is also strewed between every row of bricks in the clamp; lastly, they kindle the wood which communicates with the coals; and when all is burnt out, they conclude that the bricks are sufficiently burnt.

The proper burning of bricks is a matter of considerable difficulty, and requires an experienced workman; as it is necessary to maintain an equal heat throughout the whole mass, neither too little, which would leave the bricks weak and crumbly, nor too great, which would cause them to run together into a vitrified slag. This operation is much better performed in kilns than in clamps, as the fire can be kept up and regulated at discretion; while in clamps, as the whole of the fuel must be put in at once, the manufacturer is always tempted to use too little, and the outside bricks are necessarily under-burnt. These are called *samel* bricks, and are sold at an inferior price.

The legislature has often interfered to regulate the manufacture of bricks. By stat. 12 Geo. I. cap. 35, earth or clay, designed for making bricks for sale, shall be dug and turned at least once between the 1st of November and the 1st of February, and not be made into bricks till after the 1st of March, and no bricks be made for sale but between the 1st of March and 29th of September. But by stat. 10 Geo. III. cap. 49, earth may be dug for making bricks at any time in the year, provided such earth be turned once before it be made into bricks. And by the former statute, no Spanish is to be mixed with the earth or breeze used in the burning of bricks: and all bricks are to be burnt either in kilns, or distinct clamps, each sort by itself.

By stat. 3 Geo. II. cap. 22, there may be mixed with the brick-earth any quantity of sea-coal ashes, sifted or screened through a sieve or screen half an inch wide, and not exceeding 20 loads, to the making of 100,000 bricks, each load not exceeding 36 bushels. And breeze may be mixed with coal in the burning of bricks in clamps for sale, &c. Stock-bricks and place-bricks may be burnt in one and the same clamp, so that the stock bricks be set in one distinct parcel, and not mixed and surrounded with place-bricks.

For the more effectually securing the observation of these

laws, it was enacted, by 13 Geo. I. cap. 35, for the better discovery of offenders, that the master and wardens of the company of tylers and bricklayers should have power to search brick-kilns, &c.; but they having permitted, and even encouraged divers persons to make bricks contrary to the directions in the said act, by 2 Geo. II. cap. 15, they are divested of that power, and any two, three, or more persons, appointed by the justices of peace, are empowered, within 15 miles of London, to go in the day-time into any grounds, sheds, or places where any clay or earth shall be digged or digging for bricks or pan-tiles, or any bricks or pan-tiles shall be making or made for sale, and there to view, search, and inspect the same, &c. Offenders to forfeit 20 shillings for every thousand of unstatutable bricks, and 10 shillings for every thousand of such tiles; one moiety to the use of the prosecutor, the other to the poor of the parish where the offence shall be committed.

By 17 Geo. III. cap. 42, all bricks made for sale shall, when burned, be not less than 8½ inches long, 2½ thick, and 4 wide.

By 43 Geo. III. c. 69. (consolidating the excise duties) passed July 4, 1803, every thousand of bricks made in Great Britain, not exceeding 10 inches long, 3 inches thick, and 5 inches wide, is liable to a duty of 5s. and exceeding the fore-mentioned dimensions to 10s.; and every thousand of bricks made in Great Britain, and smoothed or polished on one or more sides, not exceeding the superficial dimensions of 10 inches long by 5 inches wide, is subject to a duty of 12s. and if such bricks exceed these dimensions, to the duty on paving tiles. The said duties are to be paid by the makers. An additional duty of 10d. per thousand was imposed on bricks and tiles in the ways and means for the year 1805.

The different kinds of bricks made in this country are place bricks, grey and red stocks, marle facing bricks, and cutting bricks. The place-bricks and stocks are used in common walling. The marles are made in the neighbourhood of London, and used in the outside of building; these are very beautiful bricks, of a fine yellow colour, hard, and well burnt, and in every respect superior to the stocks. The finest kind of marle and red bricks are called cutting bricks, they are used in the arches over windows and doors, being rubbed to a centre and gauged to a height. There is also a fine kind of white bricks made near Ipswich, which are used for facing, and sometimes brought to London for that purpose. The Windsor bricks, or fire-bricks, which are made at Hedgerley, a village near Windsor, are red bricks, containing a very large proportion of sand; these are used for coating furnaces, and lining the ovens of glass-houses, where they stand the utmost fury of the fire. Dutch clinkers are also imported, long narrow bricks, of a brimstone colour, very hard and well burnt; they are frequently warped, and appear almost vitrified by the heat. The use of them is for paving yards and stables.

BRICK-walls. See WALL.

BRICKS, Oil of. See OIL of Olives.

BRICK-dust. It is a custom with some persons to reduce this substance to a very fine powder, and give it, instead of chalk, in the heart-burn. Many of the lozenges, so much famed for the cure of this disorder, and sold under the pompous name of coral lozenges, are only made of a mixture of this uncouth medicine, and sugar, made into the consistence of paste, with gum tragacanth reduced to a mucilage with rose-water.

BRICK is also used in speaking of divers other matters made in the form of bricks.

In which sense, we say a penny-brick, or brick-bread. Some also mention brick-tin, a sort of tin in that shape

brought from Germany; and brick-loap, made in oblong pieces, from a pound and a half to three pounds.

BRICK, *πλινθιον* or *πλινθια*, *laterculus*, in the *Military Art*, denotes one of the forms of the Grecian army, which was drawn up in the figure of a brick or tyle, with four unequal sides; its length being extended towards the enemy, and exceeding its depth. That of the brick inverted, denominated *πυργος*, *turris*, was an oblong square, after the fashion of a tower, with the small end towards the enemy. Homer. *Iliad*. μ. v. 43.

BRICKS, or BRIQUES, in *Heraldry*, are figures or bearings in arms, resembling a building of bricks; being of a square form, like billets; from which they only differ in this, that they shew their thickness, which the other do not.

BRICK earth, in *Agriculture*. See *Brickish* SOIL.

BRICK kiln, a place to burn bricks in.

BRICK-layer, an artificer whose business it is to build with brick, or make brick work.

Brick-layers work or business, in London, includes tiling, walling, chimney work, and paving with bricks and tiles. In the country, it also includes the mason's and plasterer's business. The materials used by brick-layers, are bricks, tiles, mortar, laths, nails, and tyle-pins. Their tools are, a brick-trowel, wherewith to take up mortar; a brick ax, to cut bricks to the determined shape; a saw, for sawing bricks; a rub-stone, on which to rub them; also a square, wherewith to lay the bed or bottom, and face or surface of the brick, to see whether they be at right angles; a bevel, by which to cut the under sides of bricks to the angles required; a small trammel of iron, wherewith to mark the bricks; a float stone, with which to rub a moulding of brick to the pattern described; a banker to cut the bricks on; linepins, to lay their rows or courses by; plumb-rule, wherewith to carry their work upright; level to conduct it hori-

zontal; square, to set off right angles; ten-foot rod, wherewith to take dimensions; jointer, wherewith to run the long joints; rammer, wherewith to beat the foundation; crow and pick-ax, wherewith to dig through walls.

The London brick-layers and tylers make a regular company, which was incorporated in 1568, and consists of a master, two wardens, twenty-eight assistants, and one-hundred and eight on the livery.

A brick-layer and his labourer will lay in a day about 1000 bricks, in whole work, on a solid plane, when the wall is but a brick and a half, or two bricks thick; and since a cubic yard contains 460 bricks, he will lay above two cubic yards in a day: and hence it may be easily computed how many brick-layers are required to finish a certain piece of work in a given time.

Brick-laying is one of the arts subservient to architecture. Moxon has an exercise express on the art of brick-laying, wherein he describes the materials, tools, and methods of working used by brick-layers. See *Brick Walls*.

BRICK-work. There is very little to be added under this head, to what has been said in the preceding article, to which the reader is referred.

Bricks, when used in external walls, are generally worked in what is called Flemish bond, that is, with headers and stretchers alternately, and the courses so disposed, that the middle of the bricks of one fall over the joints of the next. Brick-work is measured by the square foot reduced to the thickness of one brick and a half; thus a wall two bricks thick, ten feet long, and three feet high = 30 square feet would be called 40 feet reduced. It is valued by the rod of 272 feet. Facing and gauged arches are measured by the superficial square foot, and cornices by the foot running or the length.

Bridge

BRIDGE, in *Architecture*, from the Saxon *bric*, is a structure of carpentry, masonry, or iron-work, built over a river, canal, or valley, for the convenience of passing from one side to the other, and may be considered as a road supported in the air by arches or lintels, and these again supported by proper piers or buttments.

Bridges generally form the continuation either of an highway or of a street; in the first case they are frequently built in a rude and cheap manner, and too often without proper attention to those principles which would ensure permanence and solidity to the structure; but when they take their lead or direction from a principal street in a capital city, their construction is attended with great expence, and a degree of elegance and durability is required in their formation, which calls for the utmost judgment and skill in the architect. The magnitude of bridges also varies with their situation. When they are erected in places not much frequented, they are often,

without any impropriety, made about eight or ten yards wide, but the breadth of a bridge for a great city should at least be such as to allow a safe and easy passage for three carriages, and two horsemen abreast, and for three or four foot passengers in the same manner on each banquet.

A stately bridge over a large and rapid river, while it is one of the most difficult, is justly esteemed one of the most noble and striking specimens of human art. To behold grand arches composed of an immense quantity of small materials, so disposed and united together as to form one compact body, which, bestriding the stream, affords above an ample communication with the distant shores, and allows below an uninterrupted passage to navigation, is enough to awaken the admiration of every spectator. The art of bridge-building, accordingly, has received considerable attention from writers on architecture, the earliest of whom is Alberti, who
has

has given several judicious precepts, which, with little alteration, were afterwards laid down by Palladio, Serlio, and Scamozzi. The best of these rules are also given by Goldman and Baukhurst, and by Hawkeemoor in his history of London bridge. M. Gautier has a considerable volume upon bridges ancient and modern. M. Belidor has treated on this subject, in his "Archit. Hydraulique;" and M. Parent, in his "Essais and Recherches Mathemat." vol. iii. De la Hire, too, has touched upon the subject, in his "Traité de Méchanique;" Perronet also has given the result of his experience in a magnificent work, which has acquired great credit in France; Bossut has given an excellent treatise in the "Mémoires de l'Académie;" and Regemortes, in the year 1771, published an account of a bridge constructed by him on the river d'Allier at Moulins. This bridge consists of thirteen arches, 64 feet span each, and 24 feet high; semi-elliptical.—The top of the bridge is level. Mr. Rion published, in 1760, "Short Principles for the Architecture of Stone Bridges;" and Mr. Semple has given some excellent practical remarks in his "Treatise on Building in Water," published in 1776. Other writers on the subject of arches and bridges are Muller, Labelye, Atwood, Emerlon, and Dr. Hutton in his "Principles of Bridges."

History of Bridges.—We have no records which will enable us to trace the art of bridge-building from its first rude and imperfect state, through its various stages of improvement, to its present maturity and grandeur. It cannot, however, be doubted, that men in the earliest ages would do as our villagers do at present: the accidents of nature would present a model; a fallen tree, or a wave-worn cavern would frequently form a natural bridge, and the first bridges were composed of lintels of stone or wood, either of length sufficient to stretch from bank to bank, or when this was impracticable, supported by piers or posts placed in the bed of the river. There are still considerable structures of this kind in China, and many of them in this country on a rural scale. This method, however, would in many situations be opposed by insuperable difficulties: the frequent piers required for the support of lintels would, by contracting the water-way, increase a strong current to a dangerous, rapid torrent, impeding navigation, and undermining and destroying the piers themselves. It would, therefore, be found necessary, in constructing bridges over rapid rivers, to have the supports as few and distant, and the openings as wide as possible; this could only be effected by the use of arches of stone and trusses of wood; accordingly these inventions must have been completed before bridges of importance had become common.

The origin of arches is so obscure, and our lights so few, that it is, perhaps, impossible at this time to determine to whom this invention is due. The Egyptians, skilful as they were in architecture, do not appear to have possessed arches; their temples were roofed with slabs laid horizontally from column to column, and the openings covered with masonry lintels, or, as in the passages within the great pyramid, with courses of stones projecting over one another like inverted steps, till they met at top. Some of their tombs, however, which are excavated in the solid rock, have the appearance of vaults, as the ceilings are hollowed out in a circular form, and there are instances of hemispherical niches. Similar forms also prevail in the Hindoo excavations at Ellore, in the Deccan, and in the island of Salfette. See Mr. Daniel's Plates of Indian Antiquities and Hindoo Excavations. This practice, though it has the form, has not the principle of an arch; for it is evident that a solid lintel gains no strength by being hollowed in the middle, neither is the execution more difficult; and though both the Hindoos and Egyptians attained this step, they never, at least, there are no remains which authorize

us to suppose that they ever did make any further progress in the discovery of arches.

The Chinese are acquainted with the use of arches, and from the known adherence of this nation to ancient modes, we may attribute a very high antiquity to this practice among them. Their arches are of various forms, pointed, semi-circular, semi-elliptical, and horse-shoe shaped; their construction, as described by Mr. Barrow, is curious, "each stone, from five to ten feet in length, is cut so as to form a segment of the arch, and, as in such cases there is no key-stone, ribs of wood fitted to the convexity of the arch are bolted through the stones by iron bars, fixed fast into the solid parts of the bridge. Sometimes, however, they are without wood, and the curved stones are morticed into long transverse blocks of stone." Mr. Barrow proceeds to observe, that "there are, however, arches wherein the stones are smaller, and pointed to a centre as in ours. I have understood from the late captain Parish, that no masonry could be superior to that in the great wall, and that all the arched and vaulted work in the old towers was exceedingly well turned."

However, the most ancient arches, of whose erection we have dates, are those in the cloacæ of Rome, which were begun by Tarquinius Priscus. There are also arches in several Greek theatres, stadia, and gymnasia, among others, the theatre of Bacchus at Athens, erected, probably, 400 years before the Christian era.

The Greeks, it is well known, often neglected the most necessary objects to lavish enormous sums on works of magnificence, though destitute of any essential utility. Pericles, so far from thinking of aqueducts, could never be prevailed upon even to construct a bridge over the little Cephissus. The Romans discovered, in this respect, a more solid manner of thinking; they were, it is true, much attached to pomp, but they never neglected works of public utility: they never risked their lives unnecessarily in crossing a torrent, as the Athenians must have done previous to the arrival of the emperor Adrian; for it was Adrian who undertook to form, by a bridge, a safe communication across the Cephissus, between the territories of Attica and Eleusis, on the most frequented road of Greece. While, therefore, we ascribe to the Greeks the use of arches and vaults, properly constructed for covering various openings in their buildings, we must look to the Romans for the application of arches to bridges, and for the chief improvements in those useful structures.

The construction of the Roman bridges is best described by Bergier: they possessed all the requisites which are met with in a modern bridge; they consisted of *pile*, or piers, *fornice*, or arches, *sublices*, or buttments, *pavimenta*, and *aggeres*; the roads over in the middle for carriages, on each side of which were *decursoria*, or banquets, somewhat higher than the rest of the road for foot passengers, and separated from it by a *sponde*, or railing, and sometimes even covered over to shelter passengers from the rain, as in the Pons Ælius. Among the Romans, the building and repairing of bridges was first committed to the priests, thence named *pontifices*, then to the censors and curators of the roads, and lastly, the emperors took the care of the bridges into their own hands.

The ancient bridges of Rome were eight in number. The bridge of *Fabrizius*, which joins the island of the Tyber to the city; it is now called *Ponte Quattro Capi*, from the four heads of Janus, which are placed upon it. The bridge of *Cestius*, now called of *San Bartolomeo*, which from the other side of the island passes to Trans-Tevere. The first bridge built at Rome, which was of wood, and thence called *Pons Subicius*, was afterwards rebuilt of stone by Æmilius

Lepidus; some vestiges are still to be seen at the bottom of the Aventine mountain. The bridge called *Senatorius*, and also *Palatinus*, of which some arches remain near to Santa Maria. The bridge of *Janiculus*, which, as it was rebuilt by Sixtus IV. is now called *Ponte Sisto*. The *Milvius*, now called *Ponte Malle*. There are also, near the hospital of Santo Spirito, the remains of the Triumphal Bridge, so named because the procession of the triumphs passed over it to go to the Capitol. Near to this is the bridge of Santo Angelo, formerly called *Pons Ælius*, from the Emperor Ælius Adrianus; it was repaired by Nicholas V. and afterwards ornamented with statues by Clement IX. Of these bridges the last mentioned is the only one at all remarkable for size.

One of the most celebrated of the bridges of antiquity was that built by Trajan over the Danube. It was erected by that emperor for the convenience of sending succours to the Roman legions on the other side of the Danube, in case they should be suddenly attacked by the Daci, but demolished by his successor, Adrian, lest the barbarians, overpowering the guards set to defend the bridge, should, by means of it, pour into Mæsia and cut off the garrisons there. Some of the piers are still to be seen in the middle of the river, near the town of Warhel in Hungary. According to the description given by Dion Cassius, (lib. 68. cap. 13.) this bridge consisted of 20 piers of squared stone, each of them 150 feet high above the foundation, 60 feet in breadth, and 170 feet distant from each other, which was the span or width of the arches, so that the whole length of the bridge was nearly 1500 yards. Considerable doubt, however, is thrown on this account by Montfaucon, who observes, that in the basso relievos of the Trajan column, this bridge is represented with only four piers besides the abutments, which support three larger arches or trusses of wood, with two smaller stone arches at the extremities.

On the road from Loretto to Rome, at the bottom of the hill on which the town of Narni is situated, there are the broken remains of an ancient bridge, which appears to have been very magnificent. Its form and dimensions are stated by Agostino Martinelli, in a book printed at Rome in 1676, entitled "Descrittione de diversi Ponti effidenti sopra la Fiume Nera & Tevere." This bridge which joined two mountains, between which flows the river Nera, was of an extraordinary height, and was built in this manner by Augustus, that the inhabitants of Narni might pass on a level from one mountain to another. The whole length was 850 palms (637 feet). It consisted of four large and unequal arches; the first, which was entire in the time of Martinelli, while all the others were broken, was 100 palms (75 feet) in span, and 150 palms (102 feet) in height; the second arch 180 palms (135 feet) in span; the third 152 palms (114 feet); and the fourth, which abutted against the other mountain, 190 palms, or 142 feet.

The *Pont du Gard*, about 3 leagues from Nîmes, is a very considerable Roman work. This structure was at once a bridge over the river Gardon, and an aquæduct which carried water to Nîmes. The first row of six arches, which is the bridge, supports a second arcade of eleven arches, which is continued upon the slope of the two mountains forming the valley; above the second is a third arcade of 35 arches, much smaller than those below, supporting the canal on a level with the two mountains, along which the water was conducted to Nîmes by a continued aquæduct. This remarkable edifice is built of stones of an extraordinary size, connected together without cement by iron cramps. The length of the first arcade is about 465 feet, of the second 780, of the third 850, and the height from the river 190 feet.

The celebrated Roman bridge *Pont, St. Esprit*, near Lyons, has long been reckoned one of the finest and boldest of the ancient bridges in France. Its whole length is upwards of 800 yards; it is very crooked, bending in many places, and making several unequal angles, especially in those parts where the Rhone has the strongest current. The arches are from 15 to 20 fathoms wide, and have their feet, or the bottoms of the piers, protected by two pedestals which project from them; the lower part of the piers consists of several courses of footings jutting out like steps. Between the great arches there are smaller arches like windows that come down nearly to the top of the pedestals, about the middle of the pier. This mode of construction was adopted with a view of breaking gradually the mighty force of the Rhone, the several courses of steps jutting out from the piers were intended to oppose and break the stream by portions, and prevent it from coming with its whole force at once upon the fabric; and when the flood should rise so high as to cover the steps and pedestals, then the small window-like arches would assist to convey the water through, which might otherwise endanger the great arches.

The bridge of Brioude is of great antiquity, and very remarkable, as the largest stone arch with which we are acquainted. This bridge has only one arch, under which passes the whole stream of the river Allier. The arch is formed of two ranks of squared stones; all the rest of the fabric is of rubble work. The two extremities of the arch are founded upon the rock, which occasions the springing on one side to be higher than on the other; its span is 181 feet, and its greatest height from the water to the soffit of the arch is 68 feet 8 inches, and the width of the bridge between the parapets is 13 feet.

In the middle ages bridge-building was reckoned among the acts of religion; and a regular order of hospitallers was founded by St. Benezet, towards the close of the 12th century, under the denomination of pontifices or bridge-builders, whose office was to assist travellers by making bridges, settling ferries, and receiving strangers in hospitals or houses built on the banks of rivers. We read of a hospital of this kind at Avignon, where the hospitallers dwelt under the direction of their first superior St. Benezet. The Jesuit Raynaldus has a treatise expressly on St. John the bridge-builder.

The bridge of Avignon was begun in the year 1176, and finished in 1188; it consisted of 18 arches, and was about 1000 yards in length. Several of its arches have been destroyed by the rapidity of the current together with the force of the ice.

Over the several canals at Venice are laid nearly 500 bridges of different sizes; the greater number of them are of stone. The chief of these, called the *Rialto*, is celebrated as a master-piece of art: it consists of one flat and bold arch, nearly 100 feet span, and only 23 feet high above the water, and was built in 1588 to 1591, after a design of Michael Angelo. The breadth of the bridge, which is 43 feet, is divided by two rows of shops into three narrow streets, that in the middle being the widest; and there is in the centre an open archway, by which the three streets communicate with one another. At each end of the Rialto is an ascent of 56 steps; the view from its summit is very lively and magnificent. The whole exterior of the shops and the bridge is of marble. The foundation extends 90 feet, and rests upon 12,000 elm piles. This structure cost the republic 250,000 ducats.

The aquæduct bridge of Alcantara, near the city of Lisbon, is one of the most magnificent works of the kind ever executed. It was begun in the reign of John V. king of

Portugal, in the year 1713, and finished the 6th of August 1732. The architect, under whose inspection it was begun and finished, was the brigadier Mansel de Maya. The streams which pass through this duct, for the use of the inhabitants of the city of Lisbon and villages adjacent, have their chief supply from a spring near the Riberia de Caranque, about three leagues and a half from Lisbon, where the aqueduct commences; and the water is conveyed from thence through the hills by subterraneous passages, where some other springs unite with it, and across many valleys on the tops of ranges of very magnificent arches, of which that crossing the vale of Alcantara is the chief. From a subterraneous course the water is conveyed through the building on the top of the arches by means of two channels, each of which is about 12 inches deep; it generally flows about the depth of 7 inches, and is an abundant and never-failing supply of water to Lisbon. The interior height of the building is about 13 feet; and through the centre, between the streams, is a wide handsome walk or foot-path, paved with beautiful free-stone. The building is continued the same height and width through the whole of the aqueduct from Lisbon to the spring, near the Riberia de Caranque, so that if by accident any part becomes out of repair, the workmen have easy access to it. The subterraneous passages are lighted and ventilated by frequent openings made from the surface of the earth into the aqueduct; and over each of these openings turrets or square towers are erected, which have windows latticed with iron bars to admit the light and air, and at the same time to prevent mischievous persons from throwing any thing into the building to injure it.

This pile is lighted and ventilated by 79 windows and 16 turrets; the former are three feet seven inches long by 13 inches wide, railed with iron and latticed with bars; the latter rise 23 feet six inches above the roof, and are 16 feet square; beneath every second turret is an arched door-way into the aqueduct on each side of the building, wherein the water flows, and between that building and a parapet wall is a foot-path leading from Lisbon towards the very pleasant village of Bemfique, about 4 miles from Lisbon, where several gentlemen have their quintas or country-seats: one in particular, the quinta of Gerard de Visme esq. an English merchant of the first eminence, must not pass unnoticed; it is a perfect palais enchanté, whose shady bowers, beautiful gardens, fine ponds, purling streams, and sportive fountains, are frequently honoured with visits by the queen and royal family.

The water channel under the grand arch is about 24 feet wide, and seven feet deep, but, except in very rainy seasons, no water passes through this channel; the small running stream constantly passing through the vale of Alcantara is conveyed by a very narrow channel under the pavement through the grand arch, and then continues its course through the valley, in a stream between two and three feet wide till it empties itself into the Tagus at Alcantara bridge, about the distance of two miles from the aqueduct. The expence attending the execution of so magnificent a work, and keeping the same in repair, has been immense, yet the small tax of a single rey on every pound of meat, raises a fund sufficient for the purpose. There is a chapel seen through the eleventh arch, dedicated to Nossa Senhora dos Terramotos, our Lady of the Earthquakes; in commemoration of that dreadful event the earthquake in 1755, when the greatest part of the city of Lisbon, with most of her stately buildings, and magnificent temples, were levelled with the ground.

The width of the different Arches are as under:

Number.	WIDTH.		Number.	WIDTH.	
	Feet.	Inches.		Feet.	Inches.
1	22	0	19	44	4
2	29	0	20	36	5
3	43	0	21	36	5
4	43	0	22	36	5
5	56	0	23	35	5
6	60	0	24	29	2
7	70	0	25	29	2
8 <i>Grand A.</i>	108	5	26	29	2
9	72	0	27	29	2
10	65	10	28	29	2
11	65	10	29	29	2
12	65	10	30	21	10
13	54	8	31	21	10
14	54	8	32	21	10
15	54	7	33	21	10
16	44	4	34	21	10
17	44	4	35	21	10
18	44	4			

The height of the grand arch is 227 feet, and the total length of the piers and arches 2464 feet.

Several of the bridges in France are remarkable for their size and boldness of construction, among which may be mentioned the bridge of Neuilly, built by M. Perronet, over the Seine, on the alignment of the great avenue of the Champs Elysées, in front of the palace of the Tuilleries. This bridge, which is level at top, consists of five equal arches of 120 feet French (128 feet English) in span, and 30 feet French (32 feet English) rise. The arches are oval, composed of eleven arcs of circles of different diameters; thus the upper portion of the arch was formed with a circle of 160 feet radius, which, by its settlement during the building, and after the striking of the centres, was flattened, till it became an arc of a circle of 259 feet radius, differing so little from a platband, that, as Perronet observes, the rise of the curve, in a length of 33 feet, amounted only to 6 inches 9 lines. The piers are 14 feet wide, and the breadth of the bridge 48 feet. It was begun in the year 1768, and terminated in 1780.

The bridge on the Seine, at Mantes, consists of three arches, that in the centre having an opening of 120 feet French (128 English), and the two others 108 feet French (116 English); the piers being 25 feet 6 inches wide, and the abutments 29 feet. This structure was begun by M. Hupeau in 1757, and completed by Perronet.

The bridge of Pont-Sainte-Maixence, on the river Oise, on the great road from Paris into Flanders, is also a work of Perronet's. This bridge, which is 41 feet wide, has three arches of 77 feet opening each, being a segment of a circle described with a radius of 118 feet. Each pier is singularly composed of four cylindrical pillars 9 feet diameter, leaving, therefore, three spaces or intercolumniations between them, which are arched over, the two external ones closed with a thin walling, and the middle one left open.

The bridge over the Loire, at Orleans, is composed of nine arches, which spring at 12 inches above low water; the middle arch is 106 feet in span, with a rise of 30 feet; the two arches at the extremities being 98 feet wide and 20 feet high, and the others in proportion; the four middle piers 19 feet, the four others 18 feet, and the abutments 23 feet 6 inches thick, making the whole length 1100 feet; the arches are oval, described from three centres. This bridge was built by M. Hupeau, begun in 1750, and finished in 1760.

We have many bridges of considerable note in our own country. The triangular bridge at Croyland in Lincolnshire, which was erected about the year 860, is said to be the most ancient Gothic structure remaining entire in the kingdom. There are two circumstances in the construction of this bridge, which render it an object of great curiosity. First, it is formed by three semi-arches, whose bases stand in the circumference of a circle, at equal distances from each other. These unite at the top; and the triune nature of the structure has led some to imagine that it was intended as an emblem of the Trinity. Secondly, the ascent on each of the semi-arches is by steps paved with small stones set edge-ways, and is so steep, that none but foot-passengers can go over the bridge: horsemen and carriages frequently pass under it, as the river in that place is but shallow. For what purpose this bridge was really designed, it is difficult, if not impossible, to determine. Utility, it is obvious, was one of the least motives to its erection. To boldness of design and singularity of construction it has more powerful claims; and these qualities it must be allowed to possess in as great a degree as any bridge in Europe. Although this bridge has been erected so many centuries, it exhibits no marks of decay: twelve months ago there were no fissures to be perceived in either of the arches, and all that was missed were a mound and sceptre, which have been torn from the hands of a statue of king Ethelbert by the ruthless hand of time.

London bridge is in the old Gothic style, and had twenty small locks or arches; but there are now only 19 open, two having lately been thrown into one in the centre. It is 940 feet long, 44 high, and 47 clear width between the parapets. The piers are from 15 to 35 feet thick, with sterlings projecting at each side and end, so that the greatest water-way, when the tide is above the sterlings, is 545 feet, scarcely half the breadth of the river; and below the sterlings the water-way is reduced to 204 feet, causing a dangerous fall at low water. London bridge was first built with timber in the reign of Ethelred, between the years 993 and 1016; it was repaired, or rather rebuilt of timber in 1163, and the present stone bridge was begun under king Henry II. in 1176, and finished under king John in the year 1209. It is probable there were no houses on the bridge for upwards of 200 years, since we read of a tilt and tournament held on it in 1395. Houses were erected upon it afterwards, but being found a great inconvenience and nuisance, they were removed in 1738, and the avenues to the bridge enlarged, and the whole made more commodious: the two middle arches were then thrown into one, by removing the pier from between them. The expence of the repairs amounted to above 80,000*l*.

There were other bridges in England built in the manner of London bridge; as the bridge at Rochester, which is 550 feet long, and has 11 arches; also the late bridge at Newcastle upon Tyne, which was broken down by a great flood in the year 1771, for want of a sufficient space for water-way through the arches. The longest bridge in England is that over the Trent at Burton, built by Bernard abbot of Burton, in the 12th century. It is all of squared free-stone, and is strong and lofty, 1545 feet in length, and consisting of 34 arches.

The bridge at Blenheim consists of three arches, the chief of which spans 101 feet 6 inches.

Near Old Aberdeen there is a bridge over the river Don, very much celebrated. It is in the Gothic taste. There is also a remarkable bridge called Sarah or Island bridge, built over the Liffey above Dublin, in the year 1792, by Mr. Alexander Stevens, a mason from Edinburgh: it consists of a single elliptical arch 106 feet span, and only rising 22 feet;

it is therefore six feet wider than the Rialto at Venice, and one foot less in height.

But the most extraordinary bridge in Great Britain is, doubtless, that over the river Taff, near Llantrisant, in Glamorganshire, called in Welsh *Pont y ty Prydd*. This is the work of William Edwards, an uneducated mason of the country, who was only indebted for his skill to his own industry and the power of his genius. He had engaged, in 1746, to build a new bridge at this place, which he executed in a style superior to any thing of the kind in this or any part of Wales, for neatness of workmanship, and elegance of design. "It consisted of three arches, elegantly light in their construction. The hewn stones were excellently well dressed and closely jointed. It was admired by all who saw it. But this river runs through a very deep vale that is more than usually woody, and crowded about with mountains. It is also to be considered, that many other rivers of no mean capacity, as the Crue, the Bargoed Taff, and the Cunno, besides almost numberless brooks that run through long, deep, and well-wooded vales or glens, fall into the Taff in its progress. The descents into these vales from the mountains being in general very steep, the water in long and heavy rains collects into these rivers with great rapidity and force, raising floods, that in their descriptions would appear absolutely incredible to the inhabitants of open and flat countries, where the rivers are neither so precipitate in their courses, nor have such hills on each side to swell them with their torrents. Such a flood unfortunately occurred after the completion of this undertaking, which tore up the largest trees by the roots, and carried them down the river to the bridge, where the arches were not sufficiently wide to admit of their passage. Here, therefore, they were detained. Brush-wood, weeds, hay, straw, and whatever lay in the way of the flood, came down, and collected about the branches of the trees, that stuck fast in the arches and choked the free current of the water. In consequence of this obstruction to the flood, a thick and strong dam, as it were, was thus formed. The aggregate of so many collected streams being unable to get any further, rose here to a prodigious height, and, with the force of its pressure, carried the bridge entirely away before it. William Edwards had given security for the stability of the bridge during the space of seven years; of course he was obliged to erect another, and he proceeded on his duty with all possible speed. The bridge had only stood about two years and a half. The second bridge was of one arch, for the purpose of admitting freely under it whatever incumbrances the floods might bring down. The span or chord of this arch was 140 feet, its altitude 35 feet, the segment of a circle whose diameter was 170 feet. The arch was finished, but the parapets not yet erected, when such was the pressure of the unavoidably ponderous work over the haunches, that it sprung in the middle, and the key-stones were forced out. This was a severe blow to a man who had hitherto met with nothing but misfortune in an enterprise which was to establish or ruin him in his profession. William Edwards, however, possessed a courage which did not easily forsake him; he engaged in it a third time, and by means of cylindrical holes through the haunches, so reduced their weight, that there was no longer any danger from it. The second bridge fell in 1751; the third, which has stood ever since, was completed in 1755." (Mr. Malkin's Tour in South Wales.) The present arch is 140 feet in span, and 35 feet high, being a segment of a circle of 175 diameter. In each haunch there are three cylindrical openings running through from side to side; the diameter of the lowest is nine feet, of the next six feet, and of the uppermost three feet. The width of the bridge is about

eleven feet. To strengthen it horizontally, it is made widest at the abutments, from which it contracts towards the centre by seven off-sets, so that the road-way is one foot nine inches wider at the extremities than at the middle.

The bridges of Westminster and Blackfriars, over the river Thames at London, are among the finest structures of the kind in Europe. The former is 1220 feet long, and 44 feet wide, having a commodious broad footpath on each side for passengers. It consists of thirteen large, and two small arches, fourteen intermediate piers and two abutments. The length of each abutment is 76 feet; the opening of each of the smaller arches is 25 feet; the span of the first of the large arches at each end is 52 feet, of the next 56 feet, and so on increasing by four feet at a time to the centre arch, the span of which is 76 feet. The two piers of the middle arch are 17 feet wide, and the others decrease equally on each side, by one foot at a time, every pier terminating with a salient right angle against either stream. The arches are semi-circular, and spring from about the height of two feet above low water. The breadth of the river in this place is about 1220 feet, and the water-way through the bridge amounts to 870 feet. The bridge was begun in 1738, and opened for passengers in 1750, at a neat expence of 218,800*l*. It is constructed of the best materials, and in a neat and elegant taste; but the arches are too small in proportion to the quantity of masonry.

Blackfriars bridge, nearly opposite to the centre of the city of London, was begun in 1760, and completed in ten years and three quarters, at a neat expence of 152,840*l*. It is an exceedingly light and elegant structure; but, unfortunately, the materials do not seem to be of the best kind, as many of the stones in the piers are decayed. The bridge consists of nine large, handsome, and nearly elliptical arches; the central arch is 100 feet wide, and the four arches on each side, reckoning towards the shores, decrease gradually, being 98, 93, 83, and 70 feet respectively, leaving a water-way of 788 feet. The whole length from wharf to wharf is 995 feet, the breadth of the carriage-way 28 feet, and that of the raised foot way on each side seven feet. The upper surface of the bridge is a portion of a very large circle, which forms an elegant figure, and admits of convenient passage over it. On each pier there is a recess or balcony, with two Ionic columns and pilasters, which stand on a circular projection of the pier above high water mark. The bridge is rounded off at each extremity to the right and left, in the form of a quadrant of a circle, rendering the access commodious and agreeable. This edifice must be regarded as a fine specimen of Mr. Mylne's ingenuity and judgment, though the method of construction has never been made public.

Besides the bridges already mentioned, there are many other neat and elegant structures in different parts of Great Britain and Ireland. The bridge over the Tecs at Winton in Yorkshire, was designed by sir Thomas Robinson, and built by John Johnson, a common mason at Walsingham, in the year 1762. It consists of a single arch 108 feet 9 inches span; is built of rubble-stone; and cost only 500*l*. An elegant stone bridge has lately been built over the Tweed at Kelso, upon the plans and under the direction of Mr. John Rennie. This has five elliptical arches of 72 feet span each; is quite level at top. It has two Doric pilasters, which stand on a circular projection of the pier, with a simple block cornice. The cost of this bridge was about 13,000*l*. exclusive of the roads at each end, which cost about 3000*l*. more, in all 16,000*l*.

The bridge over the Pease, or rather Peaths, on the road from Dunbar to Berwick upon Tweed, is rather an uncommon structure. This bridge crosses a deep ravine called the

Peaths. It consists of four semi-circular arches. That at the east side of the ravine is 54 feet span; the second 55 feet; the third 52 feet, and the further or western arch 48 feet. The height of the bridge, from the bottom of the ravine to the surface of the road, is 124 feet. The situation is beautiful, and has a most romantic appearance. It was designed and built by the late Mr. David Henderson, architect in Edinburgh, and does him considerable credit.

The aqueduct bridge, constructed by Mr. Rennie on the river Lune at Lancaster, is one of the most magnificent works of the kind which has been erected for the purposes of navigation. At the place where it is built, the water is deep and the bottom bad. It consists of 5 arches of 70 feet span each, and about 39 feet above the surface of the water. It has a handsome cornice, and every part of it is finished in the best manner. The foundations are laid at the depth of 20 feet under the surface of the water, and stand on a flooring of timber, supported by piles. The foundation alone cost 15,000*l*. The superstructure cost above twice that sum, although the stone was found within about a mile and a half of the place where the aqueduct was built. Barges of 60 tons burthen navigate the canal. The total height from the surface of the river to the surface of the canal is 51 feet.

It may be observed in this place, that the Romans always, without any exception that we are acquainted with, made their arches either of a semi-circle, or of a lesser segment of a circle. The voussiors were generally included between two concentric curves, on which account these are called extradosed arches. The earlier Italian architects followed the example of the Romans in the forms of their arches, which are either semicircular, or of a smaller segment, called by them *arco intiero*. and *arco scemo*, from which term our workmen have taken that of *skeme arch*. Elliptical arches are very much used by the engineers of France, most of the bridges in that country being in this manner. The French distinguish their arches into three kinds, *l'arc plein-centre*, *l'arc surbaissé*, and *l'arc surbaissé*; the first is a semi-circle, the second higher, and the third lower than a semi-circle, being formed by the greater or smaller axis of an ellipse; in practice, however, these are generally composed of several arcs of circles of different diameter, as in this case the joints are more easily traced. The arcs surbaissés are also called *anse de panier*. The *arc bombé* is an arc surbaissé, formed by a segment of a circle.

The ancients always laid their wrought stones without mortar between the joints, frequently using iron cramps to connect them more firmly together. Their large arches, and those which had to bear very great weights, were composed of several ranks of voussiors extradosed, and breaking joint, as is seen in the great cloaca of Rome, and in several bridges and aqueducts. Modern architects, however, generally use only one rank of voussiors, each of which is terminated at top by a horizontal joint, and laterally by a perpendicular joint, for the purpose of ranging better with the courses of the haunches and spandrels.

The decoration of bridges ought to be simple and large, their beauty consisting chiefly in the proportion of the voids and solids, the contour of the arches, and apparent strength and solidity, together with boldness of construction. However, many modern architects have carried simplicity to excess, particularly in Paris, where the arches of all the bridges are plain, and without any member of architecture. A happy introduction of rustic work of various forms and sizes breaks the monotony of the large masses, and enriches the edifice. This method was often employed by the ancients, and we never find that they neglected to ornament the arches of their bridges with archivolts more or less rich.

Palladio, in all his designs of bridges, has never omitted this simplest and best decoration of arches. Cornices and balustrades also are both useful and ornamental in these structures.

Generally speaking, large arches are more expensive than smaller. In a bridge lately designed over a river, wherein the foundations were very difficult to construct, one design with three arches of 116 feet each, was estimated at 13,174*l*. and another of five arches of the same kind was estimated at 12,041*l*., which was contracted for and built for the above sum.

Wooden bridges now demand our attention. The simplest case of these edifices is that in which the road-way is laid over beams placed horizontally, and supported at each end by piers or posts. This method, however, is deficient in strength and width of opening: it is therefore necessary, in all works of any magnitude, to apply the principles of trussing, as used in roofs and of arches. Wooden bridges of this kind are stiff frames of carpentry, in which, by a proper disposition, beams are put, so as to stand in place of solid bodies, as large as the spaces which the beams enclose; and thus, two or three or more of these are set in abutment with each other, like mighty arch stones.

Palladio has given several very elegant designs of wooden bridges, which he thus describes. The bridge of the Cismone. The Cismone is a river, which, falling from the mountains that divide Italy from Germany, runs into the Brenta a little above Bassano. And, because it is very rapid, and great quantities of timber are sent down it by the mountaineers, it was resolved to make a bridge there, without fixing any posts in the water, which were liable to be carried away by the violence of the current, and the shock of the stones and trees that continually came down. The invention of this bridge, (says **Palladio**.) is, in my opinion, very worthy of attention, as it may serve on all occasions where these difficulties may occur, and because that bridges thus made are strong, beautiful, and commodious; strong, because all their parts mutually support each other; beautiful, because the texture of the timbers is very agreeable; and commodious, being even, and in the same line with the remaining part of the street. The river where this bridge was erected is 100 feet wide; this width is divided into six equal parts; and at the end of each part, excepting at the banks, which are strengthened with pilasters of stone, the beams are placed, that form the breadth of the bridge, upon which, a little space being left at their ends, were placed other beams lengthways, which form the sides. Over these, directly upon the first, the *colonelli* (king-posts) were disposed on each side; these king-posts are connected to the beams which form the breadth of the bridge by means of irons passing through the projecting ends of the beams, and bolted and pinned through both. See *fig. 1. Plate XXXII. of Architecture*.

Palladio proceeds to describe three other methods of constructing wooden bridges without posts in the water, like the bridge over the Cismone. The bridges after the first method are to be made in this manner: the banks being strengthened by pilasters as necessity shall require, one of the beams forming the breadth of the bridge is to be placed at some distance from it, then the first strut is to be placed with one end upon the pier, and the other end abutting against the first queen-post, which is to be connected with the beams by irons. Then the second beam for the breadth is to be placed at a distance equal to the space between the first beam and the pier, which is to be supported in like manner with a strut and queen-post, and thus proceeding as far as is required, observing to have a king-post in the

middle of the length in which the struts meet both ways, and with collar beams between all the posts which stiffen and support the whole construction. Bridges after this manner are to be wider at the extremities, and contract towards the middle. See *fig. 2. Plate XXXII. of Architecture*.

The invention of the following bridge has the upper part which supports the weight in the form of a polygon, inscribed in a flat segment of a circle; the beams forming the breadth of the road-way are upheld by king-posts and irons, and the whole stiffened and supported by braces crossing one another between the king-posts. Struts at each end, reaching from the piers to the first beams, are also added to shorten the bearing, and increase the strength of the fabric. See *fig. 1. Plate XXXIII. of Architecture*.

The third design may be made with a greater or smaller arch than is here represented. The height of the bridge, in which are placed the braces between the king-posts, or rather radii, is to be an eleventh part of the span. (See *fig. 2. Plate XXXIII. of Architecture*.)

Mr. Cox, in the first volume of his *Travels*, has slightly described a very singular bridge at Wittingen, in Switzerland, the construction of which is quite simple. The span is 230 feet, and it rises only 5. The sketch (*fig. 3. Pl. XXXIII.*) will make it sufficiently intelligible. *ABC* is one of two great arches approaching to a Catenarian shape, built up of 7 courses of solid logs of oak, in lengths of 12 or 14 feet, and 16 inches or more in thickness. These are all picked of a natural shape, suited to the intended curve; so that the wood is nowhere cut across the grain to trim it into shape. These logs are laid above each other, so that their abutting joints are alternate, like those of a brick wall; or, in the language of the workmen, they *break joint*. It is indeed a wooden wall, simply built up by laying the pieces upon each other, taking care to make the abutting joints as close as possible. They are not fattened together by pins or bolts, but held together by iron straps, which surround them at the distance of five feet from each other, where they are fattened by bolts and keys. These two arches being erected, and well butted against the rock on each side, were freed from their supports, and allowed to settle. They are so placed that the intended road *abc* intersects them about the middle of their height. The roadway is supported by cross joists, which rest on a long horizontal summer-beam; and this is connected with the arches on each side by uprights bolted into them. The whole is covered with a roof, which projects over the arches on each side, to defend them from the weather. Three of the spaces between these uprights have struts, or braces, which give the upper work a sort of trussing in that part. This bridge is of a strength much more than adequate to support any load that can be laid upon it; though it is manifest, by the attempt to truss the ends, that it was the contrivance of a person ignorant of principle. It was the work of one **Ulrich Grubenhamm**, of Tuffen, in the canton of Appenzel, a carpenter without education, but celebrated for several works of the same kind.

At Schaffhausen, in Switzerland, where the Rhine flows with great rapidity, several stone bridges had been destroyed, when, in 1754, **Grubenhamm** offered to throw a wooden bridge of a single arch across the river, which is nearly 390 feet wide. The magistrates, however, required that it should consist of two arches, and that he should, for that purpose, employ the middle pier of the last stone bridge, which would divide the new one into two unequal arches of 172 and 193 feet span. The carpenter did so; but contrived to leave it a matter of doubt, whether the bridge is at all supported by the middle pier. It was erected on a plan nearly similar to the Wittingen bridge, at the expence of about 8000*l*. ster-

ling. Travellers inform us, that it shook if a man passed over it; yet waggons heavily laden also went over it without danger. We are sorry to add, that this curious bridge was burnt by the French when they evacuated Schaffhausen, in April 1799.

Besides the wooden bridges already described, there are several elegant and well constructed edifices in Great Britain; the most eminent of which was that at Walton-upon-Thames. This bridge consisted of three wooden arches, and five brick arches at each end; the middle arch was 130 feet in span, with a rise of 28 feet, constructed of three principal ribs, framed in the manner represented in *Plate XXXIV. of Architecture*. It was the design of the ingenious carpenter, Mr. Etheridge.

Iron bridges. Iron being the most abundant, cheap, and generally useful of all metals, has of late been employed in many works where great strength was required in proportion to the weight of the material: hence cylinders, beams, and pumps for steam engines, boats, and barges for canals and navigable rivers, beams and pillars for warehouses, and other large buildings, and at length bridges have been constructed of iron.

Iron bridges are the exclusive invention of British artists. The first that has been erected on a large scale is that over the river Severn, at Coalbrook Dale, in Shropshire. This bridge is composed of five ribs, and each rib of three concentric arcs connected together by radiating pieces. The interior arc forms a complete semicircle, but the others extend only to the sills under the roadway. These arcs pass through an upright frame of iron at each end, which serves as a guide; and the small space in the haunches between the frames and the outer arc is filled in with a ring of about seven feet diameter. Upon the top of the ribs are laid cast iron plates, which sustain the roadway. The arch of this bridge is 100 feet 6 inches in span; the interior ring is cast in two pieces, each piece being about 70 feet in length. It was constructed in the year 1779, by Mr. Abraham Darby, iron master at Coalbrook Dale, and must be considered as a very bold effort in the first instance of adopting a new material. The total weight of the metal is 378½ tons.

The second iron bridge, of which the particulars have come to our knowledge, was that designed by Mr. Thomas Payne, author of many political works: It was constructed by Messrs. Walkers at Rotherham, and was brought to London, and set up in a bowling-green at Paddington, where it was exhibited for some time. After which it was intended to have been sent to America; but Mr. Payne not being able to defray the expence, the manufacturers took it back, and the malleable iron was afterwards worked up in the construction of the bridge at Wearmouth.

The third iron bridge of importance erected in Great Britain, was that over the river Wear, at Bishop Wearmouth, near Sunderland, the chief projector of which was Rowland Burdon, esq. M. P. As this is the most considerable structure of the kind, it may be proper to give a brief sketch of its history. In consequence of the increasing trade and population of Sunderland and the two Wearmouths, the ancient ferry, which was almost in the middle of the harbour had become very insufficient and unsafe, so that, besides frequent delays and disappointments, several instances had occurred of the loss of lives. About the year 1790, in which Mr. Burdon was returned to parliament by the county of Durham, some gentlemen interested in the welfare of the town and neighbourhood of Sunderland, united for the purpose of removing the evils arising from the ferry, and Mr. Burdon was appointed one of the committee. Conceiving at first that a stone bridge would be proper, they began to adopt measures for its erection. An architect was

chosen to carry on the necessary works, who in due time produced plans, estimates, and a model of the intended edifice. But as the work was of considerable magnitude and importance, it was thought expedient to refer the design to the opinion of some gentlemen of celebrity for scientific and practical knowledge in and near the metropolis; their report being unfavourable, the scheme of erecting a stone bridge was abandoned. The committee, however, being now warmly engaged in the business, continued to prosecute their inquiries; and Mr. Burdon in particular being frequently called by his parliamentary duty to London, was very diligent in his endeavours to obtain information and hints from various quarters, as to the peculiar advantages and disadvantages of different materials, as well as of various modes of construction. Mr. Burdon had the good fortune to be assisted in the maturing of his plans by Mr. Thomas Wilson, a truly ingenious man, and at the same time to learn much of the construction of iron bridges from Messrs. Walkers, of Rotherham, so that at length he became persuaded that iron would be the most proper material of which to form the proposed bridge. He thought it best, however, to adhere to the ancient construction, by dividing the arch into portions in the manner of arch stones, and taking advantage of the ductility and tenacity of iron to produce an arch of that metal at least fifteen times lighter than a corresponding arch of stone, and capable of being put together upon an ordinary scaffolding, instead of an accurate centre, in a much shorter space of time.

Mr. Wilson, in conjunction with Messrs. Walkers, constructed and set up an experimental rib at Rotherham, which being found to answer expectation, the success of the experiment was communicated by Mr. Burdon to the town of Sunderland and the county; and his proposition for the erection of an iron bridge was acceded to. The first stone was laid in September, 1793; and Mr. Wilson was appointed to the superintendence of the work. The iron-work was cast by Messrs. Walkers, of Rotherham, and the arch was turned upon a very light but firm scaffolding, so judiciously constructed that not any interruption was given to the passage of the numerous vessels which navigate the busy river of Sunderland. The mode of bracing the ribs was so simple and expeditious, that the whole was put together and thrown over the river in ten days; the scaffolding was immediately removed, and the bridge opened for general use on the 9th of August, 1796.

During the period occupied in erecting the bridge, Mr. Burdon took out a patent to secure the invention of "a certain mode or manner of making, uniting, and applying cast iron blocks to be substituted in lieu of key-stones, in the construction of arches." He thus proceeds to describe his invention, which "consists in applying iron or other metallic compositions to the purpose of constructing arches upon the same principle as stone is now employed, by a subdivision into blocks easily portable, answering to the key-stones of a common arch, which being brought to bear on each other gives them all the firmness of the solid stone arch, whilst, by the great vacuities in the blocks, and their respective distances in their lateral position, the arch becomes much lighter than that of stone, and by the tenacity of the metal the parts are so intimately connected that the accurate calculation of the extrados and intrados, so necessary in stone arches of magnitude, is rendered of much less consequence. *Fig. 4. Plate XXXIII. of Architecture* represents a block of cast iron, five feet in depth from A to A, and four inches in thickness, having three arms B, B, B, and making a part of a circle or ellipse; the middle arm is two feet in length from B to C, and

the other two are in proportion. On each side of the arms are grooves (three quarters of an inch deep, and three inches broad) for the purpose of receiving malleable or bar-iron, and in each arm are two bolt holes, D. *Fig. 2.* represents two of these blocks placed together, and the joints confined to their respective positions by the bar-iron on each side of the arms as at E, E, E, which, with other similar blocks so united and bearing upon each other, become a rib. *Fig. 3.* and F, F, *fig. 2.* are hollow tubes six feet long, and four inches in diameter, having shoulders at each end, with holes answering to those of the blocks; G is a block of another rib connected with the former by the tubes F, F, placed horizontally. Through the holes in the shoulders and arms of the block and bar-iron are bolts, fastened with cotterels or forelocks, as at H, H, H, H. The blocks being united with each other in ribs, and the ribs connected and supported laterally by the tubes as above described, the whole becomes one mass, having the property of key stones cramped together." This extract serves to explain the more minute parts of the construction: a few words more will describe the structure itself.

The bridge consists of a single arch, whose span is 236 feet; and as the springing stones at each side project two feet, the whole opening is 240 feet. The arch is a segment of a circle of about 444 feet diameter, its versed sine is 34 feet, and the whole height from low water about 100 feet, admitting vessels of from two to three hundred tons burthen to pass under, without striking their masts. A series of one hundred and five blocks form a rib, and six of these ribs compose the breadth of the bridge. The spandrels, or the spaces between the arch and the roadway, are filled up by cast-iron circles, which touch the outer circumference of the arch, and at the same time support the roadway, thus gradually diminishing from the abutments towards the centre of the bridge. There are also diagonal iron bars, which are laid on the tops of the ribs, and extended to the abutments to keep the ribs from twisting. The superstructure is a strong frame of timber planked over to support the carriage-road, which is composed of marl, lime-stone, and gravel, with a cement of tar and chalk immediately upon the planks, to preserve them. The whole width of the bridge is 32 feet. The abutments are masses of almost solid masonry, twenty-four feet in thickness, forty-two in breadth at bottom, and thirty-seven at top. The south pier is founded on the solid rock, and rises from about twenty-two feet above the bed of the river. On the north side the ground was not so favourable, so that it was necessary to carry the foundation ten feet below the bed. The weight of the iron in this extraordinary fabric amounts to 260 tons; 46 of these are malleable, and 214 cast. The entire expense was 17,000*l.*

From this account of the bridge across the Wear, the attentive reader will see much to admire in its construction: it is not, however, totally free from defects. We conceive that the spandrels are very improperly filled up. It is true, that it is done in such a manner as is exceedingly light and pleasing to the eye; but the iron hoops may, we think, be easily compressed at the points of contact, and changing their shape will oppose very little resistance. As the arch forms so small a portion of a circle (about $64\frac{1}{2}$ degrees), the weight at the spring of the arch need not, according to the theory of equilibration, be double to that at the crown, to support, without danger of rising, any pressure arising from the mass of the structure itself: but in so flat and light an arch, an overload on any part must have a great tendency to bend it, and consequently tend considerably to break it, at a distant part, with all the energy of a long lever: we think, therefore, that a better form might

have been adopted than what has been put in practice at Wearmouth bridge.

The third iron bridge is that over the Severn at Buildwas, about two miles above Coalbrook Dale. An old stone bridge of three narrow arches having been carried away by a high flood in 1795, the present iron bridge was planned and built by the Coalbrook Dale Company, under the superintendence of Mr. Thomas Telford, the county surveyor, in 1796. It consists of a single arch, 130 feet in span, the rise from the springing to the soffite being 27 feet; and as it was thought necessary to keep the roadway as low as possible, the outside ribs are made to go up as high as the railing; they are connected with the ribs that bear the covering plates, by means of pieces of iron dovetailed in the form of king-posts. The plates which compose the covering over the lower ribs, are cast with deep flanches; they are laid close to each other, and form an arch of themselves. These side ribs, or arches, would have added much more to the strength of the bridge than they now do, had the materials been of a substance that would not expand or contract; but that not being the case, they, in warm weather, when they expand, rather tend to derange the other parts of the bridge than strengthen it; and the appearance of the whole is by no means pleasing.

About the same time that the bridge at Buildwas was erected, an iron bridge was thrown over the river Teme in Herefordshire. Its parts were so slender and ill-disposed, that no sooner was the wooden centre taken away than the whole tumbled into the river.

The splendid example of the bridge at Wearmouth gave an impulse to public taste, and caused an emulation among artists, which has produced many examples and more projects of iron bridges. The Coalbrook Dale Company have constructed several, among which is a very neat one over the river Parrot at Bridgewater. Mr. Wilson, the engineer, employed by Mr. Burdon, has also built several, and has lately finished a very elegant one over the river Thames, at Staines, which is by far the most complete in design, as well as the best executed, of any that has hitherto been erected. This bridge consists of a single arch, 181 feet in span, and 16 feet 6 inches in rise, being a segment of a circle of 480 feet. The blocks, of which the ribs are composed, are similar to those in the Wearmouth bridge, except that these have only two concentric arcs instead of three, as at the latter. The arcs are cast hollow, and the blocks connected by means of dowels and keys; thus obviating the great defect observed at Wearmouth, of having so much hammered iron exposed to the action of the air. Four ribs form the width of the arch, which are connected together by cross-frames. The spandrels are filled in with circles, which support a covering of iron plates an inch thick: on this is laid the roadway 27 feet wide. Two hundred and seventy tons are the weight of the iron employed in the bridge, and three hundred and thirty of the roadway.

For further practical details on the construction of bridges, the reader is referred to the articles *FOUNDATIONS in Water*, *CAISSON*, *COFFERDAM*, &c.

BRIDGES, Theory of. In considering the theory of bridges, the first objects of enquiry are, the nature of an arch, and the principles on which depend its stability and permanence. It will be seen, by referring to the article *ARCH* in this dictionary, that we have adopted the opinion of those mathematicians who conceive that an arch is kept in equilibrium, or from falling, by the weight or vertical pressure of the superincumbent wall or mass. The principles on which they proceed, have now obtained the name of *the theory of Equilibration*.

It will be readily admitted, by those who attend to these subjects, that whatever properties may be shewn to relate to a geometrical or lineal arch, considered without thickness, and of its superincumbent plane, may be easily and safely transferred to a real arch of solid materials, and the heavy matter sustained by it; for it is manifest that a solid arch may be conceived either to be generated by the motion of a lineal arch, and its plane in a direction perpendicular to that plane, or to be made up of an indefinite number of such equal linear arches and corresponding planes: and in either case, what is shewn to obtain with respect to the former, may without hesitation be applied to the latter. This the reader will keep in mind.

The first hint of a principle which we recollect, is contained in Dr. Hooke's assertion, that the figure into which a chain or rope, perfectly flexible, will arrange itself when suspended from two hooks, is, when inverted, the proper form for an arch composed of stones of uniform weight. The reason assigned for this principle is, that when the flexible festoon of heavy bodies becomes inverted, still touching one another in the same points, the force with which they press on each other in this last case, is equal and opposite to the forces with which they draw each other in the case of suspension. The curve formed by a rope, or flexible chain, of extremely small links, when thus suspended, is well known to our geometers by the name of the *catenarian curve*; by the French it is called *la chaînette*. If a curve of this kind be disposed in such a manner that its vertex shall be uppermost; and if a multitude of globes be so arranged that their centres shall be in the circumference of this curve, they will all remain motionless and in equilibrium: much more will this equilibrium subsist, if, instead of globes, we substitute thin voussoirs, having flat sides, which touch each other in directions perpendicular to the curve. In the former case, the equilibrium will be destroyed very easily, just as a globe resting on a plane surface is easily put into motion; in the latter, the equilibrium cannot be destroyed without considerable force, just as when a heavy body is placed upright on a broad flat base, it will not only stand, but will require considerable force to push it over.

Since the catenarian curve is readily described mechanically, it is no wonder that this principle of Dr. Hooke's should be very generally received; but many of those who adopted it, forgot that it could not be extensively applied, without certain modifications: these modifications, it will be seen farther on, cause this principle to coincide exactly with the true theory of equilibration. As to the contrary, it is manifest, from what we have already said, that it is only the form of a very slender arch rib of uniform thickness, and unfit for the purpose of a bridge; which requires a considerable mass of masonry to lie upon the arch and fill up the space to the roadway, thus completely destroying the equilibrium at first established in the arch itself. It would be possible, indeed, to construct a catenarian curve of equilibration, having a horizontal line for the extrados, but then the thickness of the mass above the crown of the arch must be enormous; thus, for a catenarian of 100 feet in span, and 40 feet high, the distance from the top of the arch to the horizontal extrados must have been nearly 37 feet to ensure an equilibrium. For these reasons the catenarian curve has been very seldom used in the erection of bridges.

Another principle, which was first assumed about the end of the 17th century, is, that every perpendicular column of masonry above the arch is merely kept from sliding down the arch by the next adjoining column. It is very obvious, at first sight, that this principle is not consistent with nature; it has therefore found but few advocates. When analytical expressions are deduced for the curvature of arches con-

structed on this principle, it is worth observing, that they coincide exactly with those which would flow from the supposition that the arch was in equilibrio, in consequence of having a fluid, with a horizontal surface, pressing upon every part of it.

A third principle is drawn from the consideration of the arch stones being frustums, or parts of wedges. This principle, we believe, originated in France, and has been presented in various forms by De la Hire, Belidor, Varignon, Parent, and other French philosophers, and lately by our ingenious countryman Mr. Atwood.

In the method now alluded to, it is considered what weight, in or upon a wedge, is balanced by forces acting against the sides; or what force such a wedge exerts both horizontally and perpendicularly to its sides; and thence it is computed what must be the position and shape of the contiguous wedges of given weights; or what must be their weights to a given shape and position, so as just to exert the adequate degree of resistance required by the first wedge; and so on, from wedge to wedge, till the whole is balanced. A mere arch constructed in this way, would remain in equilibrio as long as the constituent voussoirs had liberty to slide, without friction, down the respective inclined planes on which they lay. This method is, indeed, liable to many objections. First, this theory requires, that either the density or the magnitude of the respective voussoirs, from the crown to the foot of the arch, should keep constantly increasing in proportion to the differences of the tangents of the several angles, which the joints of the voussoirs make with the vertical axis of the curve. Now, if the architect should wish to change the density of his materials in the required proportion, we know not what materials he could use; for the density must always be very great towards the spring of the arch; and, in many cases, it must be infinitely great. If, on the other hand, the magnitudes of the voussoirs were gradually increased, it would be necessary that those at the spring, and consequently the abutments, should be immensely great, and often infinite; besides, that the wedges must be cut to different oblique angles, very difficult in execution, and totally unsafe when erected, as the acute angles would be in constant danger of flushing off. Here, too, in real practice, there would be a total want of balance, on account of the mass of masonry and rubble work, which fills the space between the arch and the road-way. But even this is not all; the arch stones cannot be made, nor indeed ought they, to act as the true mathematical wedge, the properties of which were employed in attempting to establish the equilibrium. The wedge of these theorists is supposed to have its butting sides perfectly polished, and to have its weight or other force on its back balanced by proper equivalent forces acting perpendicularly against those sides. Now this is so far from being the case in the practice of bridge-building, that architects contrive to have the butting sides of their wedges so rough as to occasion a great deal of friction between them; and to increase the adhesion of these sides the more, they introduce between them the best and strongest cement they can procure. By these means, so far from the arch stones being kept in their places only by forces perpendicular to their butting sides; and having liberty to slide along those sides, as in the wedge theory, they are absolutely prevented from the possibility of so sliding, and in a great measure kept in their places in the arch, by forces that act even perpendicularly to those which the wedge theory requires. On these accounts, then, we conceive that, however specious and plausible this theory may appear on paper, it ought not to be admitted, since it is manifestly inapplicable to any case which can ever occur in real practice.

On the contrary, the theory which we have adopted, or that

given by Emerson in his fluxions, published in the year 1742, and which has been so ably and judiciously handled by Dr. Hutton in particular, is consistent with nature and with truth. This theory establishes an equilibrium among all the vertical pressures of the whole fabric contained between the soffit, or under-side of the arch, and the road-way over all. It is now very generally adopted by the most skilful engineers and architects, as the only true one; because it secures a balance in the whole of the ponderating matter, by making an equality at every point of the curve, between all the adjacent pressures when reduced to the tangential directions, or perpendicular to the joints, which are supposed to be at right angles to the curve of the arch in every part, as such structures naturally require them to be: for, if the joints be perpendicular to the curve, there will arise a lateral pressure, whose direction is not along the tangent; which, wanting a force to sustain it, will destroy the equilibrium, and some of the stones will endeavour to fly out.

When speaking of the principle advanced by Dr. Hooke, we observed, that by means of peculiar modifications, it was capable of universal application to cases occurring in practice, and was at the same time consistent with the theory we have assumed. This we shall now proceed to shew. In *Pl. XXXVIII. Architecture, fig. 1. is fig. 2. Pl. VI.* (referred to in the article *ARCH*) completely inverted. Let this represent a flexible chord or chain, void of gravity, hanging from the points A and G, which are fixed; at the points B, C, D, E, F, suppose weights to be suspended, (acting in the directions BH, CI, DK, &c.) proportional to the several lines Bi, Cm, Dn, Eo, and Fy. Then the case now before us will be the complete inversion of that which is first stated in *Prob. 1. article ARCH*, the drawing forces in this instance being respectively equal and opposite to the several pressing forces in that: therefore, every thing proved there, by means of the composition and resolution of forces, will be found to obtain here, only in a contrary direction. Consequently, if the number of weights hanging from the chord ADG be indefinitely increased, it will assume a curvilinear shape, similar in its nature to the arch of equilibration, only in an inverted position; and the various theorems which relate to the weights and pressures of the standing arch, apply with equal facility and accuracy to the weights hanging from the suspended arch. Whether, therefore, we consider the standing or the hanging arch, it is equally true, that in the case of just equilibration, the column either pressing or drawing at any point of the arch is reciprocally as the radius of curvature and the cube of the sine of the angle, in which the vertical line cuts the curve in that point (*Cor. 2. pr. i. ARCH*); or, since the cosecant varies as the sine inversely, the column above-mentioned is reciprocally as the radius of curvature, and directly as the cube of the secant of the curve's inclination to the horizon, in the given point.

But the analogy between the standing and the hanging arch has been traced out, not so much for the purpose of corroborating the true theory of equilibration, as for the sake of deducing from it a very popular and general mode of construction; strictly accurate in its principle, and yet so simple in its application, that the most illiterate artist may safely practise it. Suppose it were required to ascertain the form of an arch which shall have the span AG (*fig. 2. Pl. XXXVIII. Architecture*) and the height D B, and which shall have a road-way of the form BEC above it. Let the outline figure ABECG be inverted, so as to form a figure A *bec* G. Suspend a fine chain of uniform thickness from the points A and G, and of such a length, that its lower point will hang a little below *d*, corresponding to D. Divide AG into a number of equal parts (the more the better) in the points 1,

2, 3, &c. and draw vertical lines, cutting the chain in the corresponding points 1, 2, 3, &c. Now take pieces of another chain, whose links are easily separated, and hang them on at all the points 1, 2, 3, &c. of the chain A d G: trim these pieces of chain, by taking off links at some places, and hanging on at others, till their lower ends all coincide with the inverted road-way *bec*. The greater lengths hung on in the vicinity of A and G, will pull down those points of the chain, and cause the middle point *d*, which is less loaded, to rise a little, and bring it near to its proper height. It is obvious this is an arch of equilibration for a bridge so loaded, that the weight of the arch-stones is to that of the superincumbent matter between the arch and road-way, as the weight of the chain A d G, is to the sum of the weights of all the little bits of chain, very nearly. But this proportion is not known before-hand; we must, therefore, proceed thus: adapt to the curve produced in this way such a thickness of the arch-stones as may be thought sufficient to ensure stability; then compute the weight of the arch-stones, and the weight of the rubble, or other materials with which the haunches are to be filled up to the road-way. If the proportion of these two weights be nearly the same with the proportion of the weights of the chain, we may rest satisfied with the curve now found: but if it be much different, we may soon find how much should be added to, or taken from, the appended bits of chain, in order to make the two proportions equal. We shall then have a curve infinitely near to the inversion of the curve wanted. This method we can safely recommend, as we know it to have been frequently used with facility and success.

It would draw us far beyond the limits we are obliged to assign ourselves, were we to give a complete view of the theory in all its branches: those who are desirous of obtaining a more intimate acquaintance with the subject are, therefore, referred to Dr. Hutton's ingenious treatise on bridges; for our own parts, we must content ourselves with just touching upon a few of the most important particulars. Under the article *ARCH*, and the corresponding plate, we have given figures of the extrados, of a circular and elliptical arch of equilibration; from which it may be seen how far the extrados extends from the vertex of the curve, before it becomes unfit for a road-way by reason of its bending upwards: in this respect, it appears, that the flat ellipsis has the advantage of the circular arch; but the cycloidal arch of equilibration, though similar to these, has the advantage of both, because the extrados runs farther on, nearly parallel to the arch before it comes to the point of inflection. We should observe, however, that in many cases, even of circular or elliptical arches, the evil arising from the inflection of the extrados may be thrown off to a greater distance, by a very simple expedient: for, in an arch of equilibration, as NBH, *fig. 3. Pl. XXXVIII. of Architecture*, whose extrados is EIK SF, since the points at *m, n, o*, &c. are kept in equilibrio by the heights of the wall *Im, Kn, Lo*, &c. if the lines *Im, Kn, Lo*, &c. be divided in a given ratio, in *i, k, l*, &c. the smaller mass, under the new extrados *e, i, k, l, f*, will still secure the equilibrium. Now it is obvious, that the lower extrados runs much farther from the crown than the upper one, before it has a point of inflection: and hence appears one great advantage arising from the use of iron in bridges instead of stone. Suppose, for instance, that an arch was to be constructed, having the span AD, and height CB, and that the necessary thickness of a stone arch at the crown was BS; here it is plain, that if the road-way were made, having a practicable slope as SK*a*, it would fall far below the required extrados at KIE, and consequently, the arch, for

want of a sufficient weight over the portion $A m n$, and an equal portion on the other side of the vertex, would be in constant danger of rising in the haunches. But a bridge formed of hollow iron vouffoires would be abundantly strong, with far less thickness over the crown, as $B s$; and then the true extrados $e i k f f$ would, in every part, have a proper slope for a road-way; while, at the same time, the structure is in no danger of being destroyed for the want of an equilibrium in all its parts.

We have mentioned under the article *ARCH*, what kind of arches ought to be preferred in the erection of bridges; and have shewn which are strongest: we may here observe, that if there be two arches of the same kind, with an equilibrated load over each of them, the strength of the one will be to the strength of the other reciprocally as the radii of curvature at the vertices of the two arches: hence an elliptical arch, standing on its shorter axis, will be stronger than a semicircular arch of the same span; and the semicircular arch of equilibration will be stronger than a flat elliptical arch of the same span. As to the effect of an additional weight over any part of an arch, it will vary in proportion of the horizontal distances from the extremities of the arch. Hence the greatest danger arising from an additional weight, is when it lies over the crown of the arch; for then the product of the horizontal distances from the abutments is equal to the square of the semi-span, and is the greatest that can be.

Since in any arch of equilibration, the pressure arising from the incumbent weight at any point is reduced to the direction of the tangent at that point, we have in any such arch $V B$, *fig. 4. Pl. XXXVIII. of Architecture*, the weight of the part $V B E A$, the pressure along the tangent $F B$, and the horizontal pressure in direction $D B$, respectively as the lines $F D$, $B F$, and $B D$, or as the corresponding lines in a triangle, whose sides are severally perpendicular to those in $B D F$. Hence, it is easy to find the area of the portion $A E V B$, thus: make $c v$ parallel and equal to $C V$, the radius of curvature at the vertex; and draw $c b$ perpendicular to the tangent $B F$, meeting $v b$ the perpendicular to $c v$ in b ; then in the triangle $c v b$, $c v$ corresponds to $D B$, and $v b$ to $D F$; and the area of the parallelogram $a v$, having $v c = V E$, is equal to the area of $A B V E$: in like manner, by drawing $c g$ perpendicular to $G I$, the tangent at G , we should have the parallelogram $b b$ equal to the portion $H B$ over the part $G B$ of the arch. The area of the space $H E V G$, between the arch and the road-way, being thus ascertained, its weight of course becomes known, and, consequently, its horizontal pressure against the abutment, as at G : for it will be, as the line $v g$: $v c$: the weight over the semi-arch: the horizontal thrust against the abutment, or a pier, at G .

But in estimating the thrust against the piers, &c. it is most common to ascertain the position of the centre of gravity of the load above the arch. Now, in cases of equilibration, this may sometimes be effected without much difficulty: for it is well known, that if a heavy body be sustained by two forces, their directions must meet, either at the centre of gravity of that body, or in a vertical line which passes through it: therefore, since the whole incumbent weight over a properly balanced arch, is sustained in equilibrio by two forces, acting in the direction of the tangents to the extreme points of the curve, the centre of gravity of the materials upon the arch will be in the vertical line which passes through the intersection of these tangents: and in most cases occurring in practice, the centre of gravity will be nearly equi-distant from the extrados and intrados of the equilibrated arch. Thus, in the curve $A V B$, loaded to the equilibrium, *fig. 5. Pl. XXXVIII. of Architecture*,

the centre of gravity of the superincumbent mass is in the vertical line $D d$, passing through the intersection of the tangents $A D$, and $B D$. And the centre of gravity of the materials $A V H K$, between the crown and the abutment, is about the middle of the vertical line $E e$, passing through the intersection of the tangents $A D$ and $B d$. If the arch be part of a circle, $i V$ is the tangent of half the arch $A V$, which, subtracted from half the span, leaves $A G =$ sine of $A V$ — tangent of half $A V$: and since $G e =$ versed sine of arc $A V$ — versed sine of arc $e V$, we shall, by adding $\frac{1}{2} E e$ to $G e$, have the altitude of the centre of gravity, from $A C$ the horizontal line. If $A V$ be a parabola, $A G = \frac{1}{2} A C$; but if it be an equilibrated curve, with a horizontal extrados, then $A G = \sqrt{\frac{V H \times C V \times R}{2 V H + C V}}$, where R is the radius

of curvature of the arch at the crown. When the arch is not justly equilibrated, other methods of finding the centre of gravity of the mass supported must be had recourse to. See Hutton on Bridges, p. 49—56. It may be worth while, however, to describe here an easy practical method, accurate enough, for most purposes: namely, to draw, on a piece of card paper, a plan of the arch, and its load; then to cut out half of it as $D A B C$, *fig. 6. Pl. XXXVIII. of Architecture*, and to determine experimentally the point K in the piece cut out, on which, when supported, the whole will rest; for this point will manifestly correspond with the centre of gravity.

The place of the centre of gravity being determined, we may now shew how to ascertain the thickness of a pier, necessary to support a given arch. Let $A B C D$, *fig. 6. Pl. XXXVIII.* represent the mass over half the arch; $D E F G$ the pier. From the centre of gravity K of the mass, draw $K L$, perpendicular to the horizon: then the weight of the arch in the direction $K L$, will be to the horizontal push, or lateral pressure at A , in the direction $L A$, as $K L$ to $L A$. For the weight of the arch in the direction $K L$, the horizontal push in the direction $L A$, and the oblique push in the direction $K A$, will be as the three sides $K L$, $L A$, $K A$. So that if A

denote the weight or area of the arch, then $\frac{L A}{K L} \cdot A$, will be

its force at A in the direction $L A$; and $\frac{L A}{K L} \times G A \times A$, its effect on the lever $G A$, to overturn the pier, or to turn it about the point F . Again, the weight of the pier will be as its area $E F \times F G$, and, supposing the load over the arch and the pier to be of similar materials, $E F \times G F \times \frac{1}{2} F G$ or $\frac{1}{2} E F \times F G^2$, is the effect on the lever $\frac{1}{2} F G$ to prevent the pier from being overturned. Here it is supposed, that the length of the pier, from point to point, is the same as the thickness of the arch, and that the centre of gravity of the pier falls in the vertical plane bisecting $F G$. Now, that the pier and the arch may be in equilibrio, the two effects just stated must be equal: therefore, we have $\frac{1}{2} E F \cdot F G^2 = \frac{L A}{K L} \times G A \times A$, from which it follows, that the thickness of the pier is $F G = \sqrt{\frac{2 G A \cdot A L}{E F \cdot K L}} \times A$.

In the above investigation, it is supposed, that the whole of the pier is out of water: but if any part of it be immersed in water, that part will lose so much of its weight as is equal to its bulk of water, if the water can get below the pier or into the joints. This, however, may easily be brought into the calculation. By applying the above theorem to the several cases which may arise, the thickness of the pier may be found, so that it shall just balance the spread

or shoot of the arch, independent of any arch on the other side of the pier. But the weight of the pier ought a little to preponderate, or exceed in effect, the shoot of the arch; and, therefore, the thickness ought to be taken a little more than what the theorem will give: indeed, in most cases occurring in practice, the thickness must be between the *fifth* and the *seventh* part of the span of the arch.

The only remaining consideration in the theory, relates to the form of the ends of a pier, so as to afford the least resistance to the force of the stream of water. Now, it may be found by a fluxional process, that if the water strike every part of the pier with equal velocity, the end of the pier should be a right-lined triangle, when the force of the water upon it is the least possible: when the variably increased velocity, as in the case of a flood, is used, the form of the ends comes out a little curved. One third of the absolute force is taken off, by making the ends of the pier semicircular; $\frac{1}{3}$ would be taken off, if the ends were parabolic; but when the ends are right angled triangles, with the right angles pointed into the stream, the absolute force of the water upon the pier is reduced to one half; and an acute angle pointed to the stream will reduce its force still more. But in rivers, on which heavy craft navigate, and pass the arch, it is generally better to make the ends nearly semicircular: for, although it does not divide the water so well as the triangle, yet it will bear the shock of the vessels better, and, at the same time, be more likely to turn them off towards the middle of the arch.

BRIDGE, in *Gunnery*, the two pieces of timber which go between the two transoms of a gun-carriage, on which the bed rests.

BRIDGE, in the *Military art*. *Flying bridge*, *pont volant*, or *pont dussarius*, signifies a bridge constructed of pontoons, leather boats, beams, hollow casks, sheaves of rushes, blown bladders, called *ascogephyri*, or the like, laid upon a river, or marshy and boggy ground, and covered over with planks, for the passage of a body of troops.

Flying bridge, *pont volant*, taken in a more particular signification, denotes a bridge composed of several boats, connected by a flooring of planks, and surrounded by a balustrade or railing. It is furnished with one or more masts, to which is fastened a strong cable, supported at proper distances by boats, and extending to an anchor to which the other end is made fast, in the middle of the water. By this contrivance, the bridge becomes moveable, like a pendulum, from one side of the river to the other, without other help than a rudder. Such bridges were formerly sometimes constructed of two stories, for the quicker passage of a great number of men, or that both infantry and cavalry might pass at the same time. The use of this kind of flying bridge is, however, attended with great difficulty and danger, and subject to the most fatal accidents. An unfortunate instance of this occurred at the evacuation of Nimeguen in the campaign of 1794, where, while the Dutch garrison were occupied in crossing the river, an unlucky shot from the French batteries carried away the top of the mast, and the bridge swinging round to the enemy's side of the Waal, above 400 of the garrison were immediately made prisoners. Those who remained in the tower, to a much greater number, bereft of the means of escape, surrendered to the besiegers.

Another kind of *flying*, or *floating bridge*, is formed of two small bridges laid over one another in such a manner, as that the uppermost stretches and runs out by the assistance of cords drawn through small pulleys, placed along the sides of the undermost bridge, which is thus pushed for-

ward, till the farther extremity of it rests against the place it is intended to be fixed upon.

When these two bridges are extended to their utmost length, so that the two middle ends meet, they should not be above four or five fathoms long; for if longer, they will break. Their chief use is for surprising out-works, or fortified posts that have but narrow moats. In the memoirs of the Royal Academy of Sciences, we find a new contrivance of a floating bridge, which lays itself on the other side of the river. Vide Hist. Acad. R. Scienc. an. 1713, p. 104.

Draw-bridge, or *pont subduciarius*, is a bridge fastened at one end with hinges, so that the other end may be lifted up or let down by some easy contrivance. The most common method is by a kind of balance called *plyers* (which see); in which case the bridge stands upright, to hinder the passage of a moat, or the like; the breadth of this bridge is usually about nine or ten feet, and its length about fifteen feet. There are others so constructed as to be drawn back, for hindering a passage, and to be thrust over again for affording a passage. Others open in the middle, half turning to one side, and the other half to the other, being joined again at pleasure; but these are subject to an obvious inconvenience, as one half of them remains on the enemy's side. The marquis de L'Hopital has given the construction of a curve, in which a weight will always be a counter-balance to a draw-bridge; which the younger Bernoulli has shown to be no other than the cycloid. Act. Erud. Lips. an. 1695.

Drawbridges are likewise frequently used on canals, navigable rivers, and wet-docks; for small canals they consist of one leaf or frame only, moveable on hinges; but for large canals, such as the Forth and Clyde canal, in Scotland, and for wet-docks, &c. they are made in two pieces which meet in the middle, forming an arch, and are raised or lowered by means of balance frames, moveable on the tops of uprights, suited in height to the magnitude of the bridge. Such bridges, however, have been found inconvenient in use, owing to the obstruction they give to the yards and rigging of ships in passing through them. This gave rise to the invention of a different sort of bridge, which, for small canals, consists of one frame or leaf only, turning on a centre or series of balls or rollers; and for large canals, or navigable rivers, they are formed of two parts, which meet in the middle. The first that have come to our knowledge are those at Cherbourg and Toulon. Neither of them, however, are so complete as those that have lately been constructed at the West India and London docks; the latter spans 40 feet, and 15 feet wide in the roadway, and is made of thin ribs of cast iron, about an inch and a half thick, turning on a number of concentric rollers, moving between two circular rings of cast iron, which are very nicely turned, and there is a flap for each leaf, which lets down by a screw, and abuts against the stone work on each side, forming the whole, when shut, into an arch, capable of carrying any weight which can ever pass over it.

The whole, though weighing 85 tons, moves with great ease, and can be opened and shut in less than three minutes, thereby occasioning very little obstruction to travellers, while vessels pass through the locks.

Bridge of communication, is a bridge made over a river, to preserve a free intercourse between two armies, or fortified places, separated by the stream.

The bridge now most generally employed, and which, by reason of its superior efficacy, has gradually almost superseded the use of all those above-mentioned, is that constructed of copper or wooden boats, fastened with stakes or anchors to the bed of the river, and covered over with

planks. Modern armies generally carry with them a number of these copper boats, or pontoons, that they may always be in readiness for throwing over bridges. Several of these being joined side by side, till they reach across the river, and planks laid over them, make all plain for the troops to march upon.

The most remote ages of antiquity furnish us with many remarkable instances of bridges of this kind. One of the earliest upon record, is that laid by Darius Hystaspes over the Ister, or Danube, in his Scythian expedition, about the year before Christ 508. Herodotus, l. iv. c. 98. Darius also crossed the Thracian Bosphorus with 700,000 men by means of a bridge of boats, the strait being five stadia, or 1008 yards in breadth. That of Xerxes in the year 480 before Christ, seven Greek stadia, or, as some estimate them, nearly a mile in length, across the Hellespont, is still more remarkable. The boat-bridges of Xerxes began at Abydos, and terminated a little below Sestos. This passage, which is the narrowest part of the strait, is only about $75\frac{1}{2}$ toises, or 800 yards wide. But, as the length of the bridges is said to have been seven stadia, M. D'Anville (M. de l'Acad. des Bell. Lettr. t. 28. p. 334.) has from thence inferred, that these stadia were only 51 toises, or 108 yards, each. The first bridge of Xerxes having been carried away by the force of a tempest, he substituted two others, that towards the Pontus Euxinus, consisting of 360 vessels of the largest dimensions used in the ancient navies; the other of 340. These were steadily moored by means of large anchors. Six immense cables, fastened to large piles driven into the opposite shores, extended the whole length of the bridges. Across these were laid trunks of trees, and upon them a flooring, which was covered with earth for the passage of the army. The whole was secured by a railing on each side. This contrivance is the model of most of the bridges of boats which have since been constructed, with this difference, that the vessels of Xerxes were arranged stem and stern upon the water, a plan exactly contrary to the present method. That the Persians were in the habit of constructing bridges of this kind, appears from these examples, and from another recorded by Xenophon, who mentions that of Sitace over the Tigris, composed of 27 boats. The Greeks and Romans were very expert in this part of the military science. Several bridges of boats are mentioned by Appian, in his account of the social war. That of Cæsar over the Rhine is familiar to the readers of ancient history; and in all his campaigns, we observe particular attention on the part of that celebrated commander with regard to the passage of rivers, or preserving communications by means of bridges. In the contest between the armies of Otho and Vitellius about Cremona, a bridge of this kind is noticed by Tacitus. That of Trajan over the Danube has been already mentioned. Where boats were wanting, the ingenuity and cruelty of the ancients found other expedients for overcoming the obstacles presented by the rivers to their progress. Hamilcar Barca, in his war against the mercenaries, crossed the Macar by means of the following stratagem. He observed that when the west-north-west wind prevailed, the sand it agitated almost choked up the mouth of the river, and formed a kind of natural bridge for the passage of his troops. He availed himself of this discovery to pass the Macar in the night, and obtain by surprise an easy victory. Sapor the Persian, by a refinement in cruelty, made use of the bodies of his prisoners to facilitate the passage of his army. (Vid. Herod. lib. iv. cap. 97, 101.—Ibid. lib. vii. cap. 33—36.—Xenophon Anab. lib. ii.—Appian, de Bel. Civ.—Cæsar de Bel. Gall. lib. iv.—Tacitus, hist. lib. ii.—Dion Cassius, hist.—Polybius, lib. i.—Trebell. Poll. in Valerian.)

Of late years the laying of bridges across rivers has been greatly improved and facilitated. In the campaigns of 1799 and 1800 in particular, this branch of the military science attained that pinnacle of excellence which it will be difficult to surpass. Few objects present more varied details than the crossing a river by open force, and in presence of an enemy. In operations of this kind, localities and other physical circumstances differ so infinitely, and give rise to such numerous combinations of advantages or disadvantages, that it is impossible to lay down any given precepts which may be very applicable in all cases. What may be very proper and feasible upon one river, or at a certain season of the year, may be impracticable elsewhere, or in any other period. Sometimes the necessities for the expedition must be transported by water; at others, by land. Rivers which have marshy banks, a smooth bed, an even current, and a muddy bottom, require totally different precautions from those with a rapid and formidable current, which are overhung with thick woods, or have a rocky bottom. The best commentary upon these several cases, will be a detailed account of the operations adopted in them.

The passages of the Rhine by the French troops at Urdingen, Neuwied, Kehl, and Diersheim; at Reunlingen, Atzmoor, and Lucistieg in Swisserland; those of the Limmat, the Danube, the Lech, the Inn, and finally of the Mincio, will evince the progress lately made in the construction of bridges of pontoons. Two of these have been treated with great precision by an engineer in the French service, whose work well deserves the attention of military men in general. (Dedon, relation des passages, de la Limmat et du Rhin. Par. 1801, 8vo.)

Under this article of *bridges* we may also mention *portable bridges*, easily taken asunder, and put together again. M. Couplet mentions one of this kind, 200 feet long, and which 40 men may carry. See Du Hamel. Hist. Roy. Acad. Scienc. l. iii. § 5. c. 4.

Pendant, or hanging bridges, called also *philosophical bridges*, are those which are not supported by posts or pillars, but hang at large in the air, being sustained only at the two ends or buttments. Of such bridges, consisting of a single large arch, instances have been already mentioned. Bridges of this kind are used by the Spaniards for passing the torrents in Peru, over which it would be difficult to throw more solid structures either of stone or timber. Some of these hanging bridges are formed so strong and broad, that loaded mules pass along them. Ullon. tom. i. 358. Dr. Wallis gives the design of a timber bridge, 70 feet long, without any pillars, which may be useful in places where pillars cannot be conveniently erected. Phil. Trans. N° 163, p. 714. Dr. Plott informs us, that there was formerly a large bridge over the castle-ditch at Tutbury in Staffordshire, made of pieces of timber, none much above a yard long, and yet not supported underneath, either with pillars or arch-work, or any other sort of prop whatever.

It has been already mentioned, that the ancient Romans paid particular attention to the construction and reparation of bridges; and that in the middle ages the building of bridges was reckoned among the acts of religion. By our ancient laws, *pontium reparatio*, or the reparation of bridges, was part of the *trinoda necessitas*, to which every man's estate was subject. However, by the great charter, 9 Hen. III. c. 15. no town, nor freeman shall be distrained to make bridges nor banks, but such as of old time, and of right, have been accustomed. And none can be compelled to make new bridges, where none were ever before, otherwise than by act of parliament. 2 Inst. 701. By the common law, some persons are bound to repair bridges by reason of the tenure

of their lands or tenements; and some by reason of prescription only. 2 Inst. 700. But if a man make a bridge for the common good of all the subjects, he is not bound to repair it; and if none are obliged by tenure or prescription at common law, then the whole county or franchise shall repair it. 2 Inst. 701. By 22 H. VIII. c. 5. it is enacted, that, as in many places it cannot be known and proved, what hundred, town, parish, person, or body politic, ought to repair bridges broken in the highways, in every such case, the said bridges, if they be without a city or town corporate, shall be made by the inhabitants of the county; if within a city or town corporate, then by the inhabitants of such city or town corporate; if part be in one shire, city, or town corporate, and part in another, or part within the limits of a city or town corporate, and part without, the inhabitants of the shire, cities, or towns corporate, shall repair such part as lies within their limits. The decays of bridges are presentable in the leet, or torn. 2 Inst. 701. By the above act, the justices, or four of them at the least, shall have power to inquire, hear, and determine in the general sessions, of all manner of annoyances of bridges broken in the highways, to the damage of the king's liege-people, and to make such process and pains upon every presentment against such as ought to be charged to make or amend them, as the king's bench usually doth, or as it shall seem by their discretions to be necessary and convenient for the speedy amendment of such bridges. Such part of the highways as lies next adjoining to any ends of any bridges within the space of 300 feet, shall be made and repaired as often as necessary; and the justices shall inquire into, and determine annoyances in such highways. By 12 Geo. II. c. 29. no money shall be applied to the repair of bridges, until presentment be made by the grand jury at the assizes or sessions, of their insufficiency, inconveniency, or want of reparation. Again, by 1 Ann. st. 1. c. 12. no fine, issue, penalty, or forfeiture,

upon any presentment or indictment for not repairing bridges, or the highways at the ends of them, shall be returned into the exchequer, but shall be paid to the treasurer, to be applied towards the said repairs, and not otherwise; and no presentment or indictment for not repairing bridges, or highways at the ends of bridges, shall be removed by "certiorari" out of the county into another court. The charges of repairing and amending bridges, and highways at the ends of them, shall be paid out of the general county rate. 12 Geo. II. c. 29. The four justices in session may appoint two surveyors, with salaries, to see the bridges amended. 22 H. VIII. c. 5. This business of surveying bridges is usually annexed by the justices to the office of the high constables, with the allowance of salaries. The stat. 14 Geo. II. c. 33. gives justices the power of changing the situation of bridges, as it enables them to purchase lands adjoining any county bridge, for the more commodious enlarging, and convenient rebuilding the same. By 12 Geo. II. c. 29. justices, at their general or quarter sessions, after presentment made by the grand jury of bridges wanting reparation, may contract for rebuilding and repairing the same, for any term not exceeding seven years, at a certain annual sum. They shall give public notice of their intention to contract, make contracts at the most reasonable prices, and take security of the contractors for due performance.

If a man has toll for men or cattle passing over a bridge, he is to repair it. And toll may be paid in these cases by prescription or statute.

By many special statutes, enacted upon the occasion, it is made felony to destroy bridges, &c. erected by virtue of these acts of parliament.

BRIDGE-MASTERS, are officers of the city of London, chosen by the citizens, who have certain fees and profits belonging to their office, and the care of London bridge, &c.

Bristol

BRISTOL, in *Geography*. This second city of England is situated on the southern extremity of Gloucestershire, and the northern of Somersetshire, and once formed part of both counties. It is seated principally on a peninsula, between the rivers Frome and Avon, and lies in $51^{\circ} 30'$ N. lat. $2^{\circ} 46'$ W. long. and is in a bearing west 117 miles from London, and 12 from Bath. Various conjectures have been formed relative to its ancient and present name. Barret, in his large

history of this city, says it received the appellation of *Caer-Oder* at an early period; but is at a loss for the origin of *Oder*. *Caer-Brito*, its original designation, was evidently the generic name it obtained while a protected city of the Britons, under the Roman forces, which were stationed at *Abone* in its immediate vicinity. From this it was changed to *Brightstow*, or *Brighticstow*, perhaps a translation of *Caer-Brito*; or it might have taken that name from

Brightick, son of Algar, and great-grandson of Alfred, who was hereditary lord of the place. Its present name, Bristol, appears to have been derived from some early Latin writers, changing it, by way of euphony, into *Bristolina*, while that of its common pronunciation, *Bristow*, is evidently an abridged mode of pronouncing *Brightflow*. It is a tradition, from an account which William of Worcester gives out of a MS. he saw in the house of the Calenderies, that *Bristow* was founded, or rebuilt by Brennus, son of Malmutius Dunwallo, who reigned a king of the Britons 380 years antecedent to the Christian era. In allusion to which two statues are placed over St. John's gate, in this city, emblematic of Brennus and Belinus, who are said to have reigned conjointly after the decease of their father. It is probable that a situation so eligible must have struck the early Britons, who therefore made it a place of associated habitation, previous to the Roman invasion; however, it is evident that it was a place of importance during that period, for Gildas, as early as A. D. 430, reckons this among the fortified and eminent cities of Britain, under the name of *Cacr-Brito*. Nennius also, A. D. 620, mentions it in his enumeration of 28 cities of Britain. On the dereliction of the island by the Romans, the Saxons overran the country and took possession of Bristol. Leland says, it was by them considerably increased; and also remarks, that St. Jordanus, a disciple of St. Augustine, sent by pope Gregory to convert the Saxons to Christianity, preached the gospel at Bristol, where he died and was buried. Thus we find it a place of note at the end of the 6th century. In *Domesday* book, finished by command of the conqueror in 1086, the inhabitants are styled *burgesses*. It was then exceeded in rate by no city, except London, York, and Winchester.

Early and present extent. The city, as first laid out at the conflux of the Frome and Avon, was, except on the northern part, where afterwards the castle was erected, insulated by these rivers. The ground rose each way to the centre, forming a pleasant hill. It was divided into four transverse streets, and walled round after the course of the river for its better defence. At the end of each street were a fortified gate and a church, and four churches surrounded the cross at the centre of the city. In this state Bristol could not exceed a mile and a half in circumference. The conflux of people drawn hither by its growing trade soon extended it beyond the walls, both on the Gloucestershire and Redcliffe side of the Avon. Other walls and gates therefore would become necessary, and it was thus further defended, before the wooden bridge was built across the Avon. Leland mentions others, which he terms "*Esternavel secunda mœnia urbis.*" Indeed, the large and strong castle, with its outworks, when completed, as it joined closely to the old town and the buildings on the southern side of the river, inclosed also by a strong wall, were great additions to the city, and thus made its circumference at least two miles and a half. The accession of the monastery of St. Augustine, with Gaunt's church and hospital to the west, the priory of St. James to the north-west, and the purchase of the castle precincts, and laying it out in streets, added very considerably to the extent of Bristol, towards the close of the 17th century. Since that period most of the buildings have been erected, both in the city and suburbs, which bear a modern appearance, and these have been numerous; so that it may be truly said, that Bristol has increased, within the last 40 years, full a fourth. This city once formed part of the Saxon kingdoms of Wessex and Mercia; and after the whole of England was subjected to one monarch, and divided into counties or shires, constituted part of the counties of Gloucester and Somerset, though it was generally considered as belonging to the latter county. It was by royal

charter, temp. Edw. III. made a county of itself; and by other different charters, its boundaries have been extended from time to time, till they now form a line on the Gloucestershire side, of $4\frac{1}{2}$ miles and 37 perches, and on the Somersetshire side $2\frac{1}{2}$ miles and 18 perches: the whole city is therefore 7 miles and 55 perches in circumference, and, taking in the suburbs from Lawrence-hill in the east to the Hotwells in the west, is more than 3 miles in length. Its breadth, from Stokes Croft turnpike on the north, to Ashton turnpike on the south, is upwards of $2\frac{1}{2}$ miles. The number of houses and inhabitants it is difficult to ascertain. In the late survey by order of government, the return from Bristol must have been very inaccurate, and is stated at 10,896 houses, and 63,645 inhabitants. Anderson, in 1758, puts the latter down at 100,000, but gives no documents for this enumeration. The houses may be stated on an average estimate at 17,000; and if the environs of Temple-street, Lewin's mead, College-place, Lime-kiln-lane, &c. be attended to, the rate of 7 to a house will not appear too high. This calculation, including those in hospitals, alms houses, &c. will bring it to about 128,000 persons, which will not far exceed the truth.

Public Buildings, &c. The buildings in the old part of the city are awkward, and the various alterations that have taken place at different periods have destroyed all uniformity. The city stands on very uneven ground, and very high walls are raised round most of the houses; but the enormous height to which they are often built, appears highly unreasonable, especially when it is considered that an enclosing wall has been known to cost the value of the house itself. This fashion is declining, and Bristol can now boast some good and handsome houses, in the open streets, squares, &c. Among the principal buildings are the Cathedral, Redcliffe Church, the Exchange, Infirmary, Public Library, Theatre, Assembly-rooms, &c.

The *Cathedral* is only part of the original building, which was the church belonging to the abbey of St. Augustine, founded by Robert Fitzharding, younger son of the king of Denmark, whose monument is still preserved within it. At the dissolution of the monastery, this noble building, then 350 feet in length, was partly demolished; but when the king determined to erect six new bishoprics, of which Bristol was one, and was informed there was enough of the fabric left for a cathedral, he put a stop to its further demolition; the western part being removed, it was left in that mutilated state in which it remains; the present fabric consists of the transept, the eastern part of the nave, and the choir. At the west end is a large square tower, highly ornamented and crowned with battlements and four pinnacles. The present church, from east to west, is 175 feet; its breadth of transept, from north to south, 128 feet; the breadth of nave and aisles 73 feet, and height of the tower 140 feet. The establishment is a dean, six prebendaries, four minor canons, sacrist, &c.; and service is performed twice every day.

The *Church of St. Mary Redcliffe*, says Camden, "is like a cathedral, and on all accounts the first parish church in England." It was founded in 1292 by Simon de Burton, who was six times mayor of Bristol. According to the mayor's calendar, this church was finished A. D. 1376, and was then celebrated for its architecture all over England. The tower and spire were 250 feet high; but in 1445 a terrible storm of thunder and lightning destroyed part of the spire, and the church was much damaged. The latter was repaired by the munificence of Mr. William Cannynge, merchant, but the spire was never rebuilt. The church stands on an eminence, called Redcliffe-hill, and is built in the form of a cross. The nave rises above the aisles, is lighted by a series of lofty windows on each side, and is supported by flying buttresses. The tower is large, and with the remain-

ing part of the spire, richly ornamented with carved work, and also a variety of niches and statues. Though a lofty and massy building, yet, from the peculiar beauty of its masonry, it has a light and airy appearance both without and within. The roof, nearly 60 feet in height, is arched with stone, and ornamented with various devices. The church, including our lady's chapel, is in length 239 feet, and the transept, from north to south, 117 feet. The breadth of the nave and aisles is 59 feet, and at the cross, nave and aisles, 114 feet. The height of the aisles both direct and transepts is 25 feet. The height of the nave is 54 feet. St. Mary's chapel has been separated from the church, and is used as a grammar-school. A peculiarity observable in Redcliffe-church is that the transept consists of three divisions, or aisles, similar to the body of the church, which has a fine effect when the spectator places himself in the centre of the building, and looks around him. Besides the above, there are 15 other parish churches in Bristol, some of which are modern structures. Temple church is rather curious, and its tower is out of the perpendicular. There are also 22 chapels, or places of worship for dissenters of different denominations, and 5 chapels of the established religion.

The *Exchange*, finished and opened in 1743, was built by Wood, the architect of Bath, at an expence of 50,000*l*. It is a handsome building, in the Grecian style, 110 feet in front, and 148 feet in depth. The principal front is upon a bold rusticated basement, the central part of which makes a tetrastyle of almost whole columns, with Corinthian capitals, supporting a pediment, in the tympan of which are the arms of England carved in stone. The place intended for the merchants is a peristyle of the Corinthian order, 90 feet by 85, and capable of containing 1440 persons.

The *General Hospital*, for the reception of all cases, and all persons of whatever nation, is a handsome edifice, though it has unfortunately never been yet completed.

The *Theatre-royal*, King-street, is a peculiarly neat and convenient structure: indeed, Mr. Garrick pronounced it to be the completest in Europe of its dimensions; and he wrote a prologue and epilogue, which were delivered at the opening, May 30th, 1766.

The *Bristol City Library*, is so called, because part of its collection belongs to the corporation, and the greatest part to a society of gentlemen. It contains an excellent assemblage of ancient and modern books, which, by donations and annual subscriptions, are rapidly increasing. They are contained in a large freestone building erected for the purpose, with a convenient house for the head librarian, who has also an assistant librarian.

The *Assembly-room*, in Prince's-street, has a beautiful front of free-stone, consisting of a rustic basement, with a central projection supporting four Corinthian columns, coupled and crowned with an open pediment. On the frieze, in relief, is the following motto: "*Curas cithara tollit*," Music dispels care.

To these may be added, the *Guilliball*, where the assizes, sessions, and other public business are transacted.

Government, civil Officers, &c.—The original government of Bristol seems to have been mixed, military and civil; the chief authority residing in the lord constable of the castle, who deputed another officer for the execution of justice, called "prepositus villæ," or provost of the town. The earliest account of this officer occurs in Domesday-book. In the reign of king John, Bristol obtained a charter to be governed, like London, by a mayor, &c. From the Annals, it appears, that the civil government, at different periods, has been variously modelled, as appears from the following list:

1. Till A. D. 1205. A prepositus under the custos of the castle.
2. 1266. A mayor and two prepositors.
3. 1313. A mayor and two seneschals.
4. 1372. A mayor and two bailiffs.
5. 1500. A mayor, sheriff, and two bailiffs.
6. To this day. A mayor and two sheriffs chosen annually.

The government of the city is now administered by a mayor, a recorder, twelve aldermen, who are all justices of the peace, two sheriffs, an under-sheriff, twenty-eight common-council-men, town-clerk, deputy town-clerk, chamberlain, vice-chamberlain, steward of the sheriffs' court, clerk of the arraigns, registrar of the court of conscience, and also a high steward. There are other officers pertaining to the corporation, as sword-bearers, two coroners, water-bailiff, quay-masters, school-masters, clerk of the markets, keepers of the prisons, inspectors of nuisances, eight serjeants at mace, criers of the court, common-crier, exchange-keeper, sheriffs' officers, club-men, city marshal, and a band of musicians in constant pay. Great form is observed on the 15th of September, in the election of mayor, when the whole body corporate is convened. He is allowed 1000*l*. for the year of his mayoralty, and the sheriffs 500*l*. each for the year of their shrievalty. The mayor has the highest marks of honour granted to magistracy, scarlet ermine gowns, sword, mace, cap of maintenance, &c. He holds a daily sessions in the council-house to hear complaints, and accommodate differences, courts of conscience, and pie-powder, quarterly sessions, and a general jail delivery twice a year: one for the decision of civil, and the other of criminal causes, wherein the court has the power of life and death. The mayor, aldermen, and common council have the custody of the city seal, which is impressed with the city arms. These are gules, a castle on a hill by the sea-side, and the helm of a ship passing by, all proper; to which were afterwards added two unicorns as supporters. The motto is, "*Virtute et Industriâ*."

From the time Bristol was made a county of itself, it has, by various charters, and grants, been endowed with additional privileges and immunities, all of which were confirmed by a new charter from queen Anne. By another of king Edward IV. 1461, Bristol was exempted from the authority of the high admiral of England by land and water; and the right of determining differences, belonging to the court of admiralty, was referred to the mayor and corporation. The jurisdiction by water extended up the river only to lower Harrate, till an act of William carried it to Hanham; thence it reaches to Kingroad and down the channel to the Flat-holmes. To this place, Gildas, the ancient British saint and historian, retired, and here he died. The opulent corporation of Bristol is possessed of large estates, both in the city and in the country; and they are the patrons of several church livings, so that they not only possess great influence, but have it in their power to encourage genius, and reward industry and merit. The city is divided into twelve wards, each of which has an alderman to preside over it. The recorder is always one of the aldermen, and, by virtue of his office, the principal. The senior alderman, as in London, is called the father of the city. Every ward has one chief constable, and twelve others, a night constable, and a proper number of watchmen under him.

Bristol contains three prisons: Newgate, at the end of Wine-street, which is a gaol for malefactors and debtors; Bridewell, or the city prison, for the confinement and correction of less offenders; and at the end of Gloucester-street is a prison, on Howard's plan, for that part of the suburbs

which stands in the county of Gloucester, and a Bridewell on the Somerset side. The act for lighting Bristol with lamps was procured in the reign of William III. This obliged the citizens to hang out their own lamps; but they are now provided, and the lighting contracted for, by the different parishes. Most of the streets are well paved on the sides with flag stones; but the pitching with pebbles in the carriage-way is at present extremely uneven and bad, and requires amendment. The poor rates are separately assessed, and collected on the respective parishes; but the poor are taken care of conjointly, and have a house called St. Peter's hospital. There are fourteen stands of hackney coaches in various parts of the city, and one at Dowry square. Each coach is numbered, and marked C. B. There has lately been instituted at Bristol a society for the suppression of vice.

Bristol appears to have been a *borough* at the Conquest, and at a very early period, by ancient prescription, sent two burgesses to parliament. A list of its representatives is still extant from the 23d of Edward I. 1295. None can vote for members but such as are free of the city, which freedom is attained by servitude, by hereditary right, by marrying a freeman's daughter, or by purchase. The number of freemen, at present, is about 8000. The city gives title to an earl, and the earldom was formerly in the noble family of Digby, but is now in that of Hervey.

Commerce, Trade, Shipping, &c.—That a port so situated as Bristol should have early participated in the commerce of the country, can be no matter of surprise. William of Malmesbury, in 1139, says, it was a place much addicted to trade, and was then full of ships from Ireland, Norway, and every part of Europe, which brought hither much commerce, and great foreign wealth. From the charter of king John something may be learnt of the commerce of the place in his reign, but more will be furnished by that of Edward III. Bristol was grown so opulent in 1327, that the mayor and commonalty lent the king (Richard II.) 500 marks, which is the first instance (except London) in the Fœdera of a lay community lending money to the crown; and, in future loans, we find Bristol follow London. In 1487, a petition was presented to the king, to empower the citizens of Bristol to remove all obstructions in the river Avon that impeded its navigation between Bristol and Bath; for before the time of Richard I, the Avon was navigable to Bath. In 1711, an act of parliament was obtained, at an expence of 15,000l. to amend this navigation by placing weirs, locks, and other obstructions. In the roll of the fleet of Edward III. which was at the siege of Calais, in 1347, we find the proportion of ships and men furnished, on that occasion, by London and Bristol: the former supplied 25 ships, and 662 men, and the latter quota was 22 ships, and 608 men. William Cannynge is distinguished as a great merchant here in 1449, and he appears to have traded with peculiar privileges, to Prussia, the Hanseatic towns, and Denmark. William of Worcester says, that Cannynge employed for eight years, in his own shipping concerns, 800 men, and he specifies the ships and tonnage employed by him. The same Cannynge paid king Edward IV. 4000 marks for his peace, i. e. for leave to trade to prohibited places, and to be free of imposts and duty.

The commercial character of the Bristol merchants will best appear from the letters patent which were granted to John Cabot, a Genoese by birth, but a resident merchant in this city, and to his three sons, who fitted out vessels for the purpose of discovery. In 1527, Robert Thorn obtained leave to go on a voyage of discovery, to find out a north-west

passage. In 1583, sir Humphrey Gilbert performed a voyage for the colonization of America, an account of which is given in Hackluyt. Many other voyages were afterwards made from Bristol, with the like public-spirited views, though not with equal success. The merchants had, previous to 1526, traded to St. Lucar in Spain, and thence to the Canaries, sending out cloth, soap, &c. and bringing in return sugar, drugs, dye-stuff, &c.; and De Wit, in his interest of Holland, says, this city very early engaged in the cod-fishery on the coast of Newfoundland, and also entered into the West India trade soon after the discoveries were made. In 1556, the merchants were incorporated into the society called Merchant Venturers: and various grants, immunities, and franchises, were annexed to their society. Sebastian Cabot was constituted the first governor. In 1588, four ships were fitted out from Bristol to join the Queen's fleet at Plymouth. With regard to the present state of trade, it is very considerable to Florida, Carolina, Virginia, New York, Newfoundland, Quebec, Spain, Portugal, West Indies, Denmark, Sweden, Russia, Prussia, &c. The ardour for the African trade seems much to be abated; and the Bristolians now yield the palm of traffic in human beings to the rival port of Liverpool. The merchants in Bristol trade with a more entire independence on London than any other port in Britain. Whatever exportations they make to any part of the world, they can import the full returns, and find a market, without consigning their ships or cargoes to London. They have buyers at home for their largest importations, consequently the shopkeepers of Bristol, most of whom are wholesale dealers, keep up a great inland trade, having riders and carriers, like the London merchants.

The quay of Bristol, which was commenced where the bed of the Frome was altered, reaches round from the stone bridge on the Frome, to the new handsome bridge over the Avon; in extent one mile, being one uninterrupted wharf of hewn stone, with sufficient depth of water, at flood tides, for the largest ships to ride close to the walls, and discharge their cargoes. Thence, as the tide ebbs, ride safe at their moorings on a soft oozy bed of mud; but foreign and sharp keeled ships are often strained, and obliged to go into dock after lying here. This occasioned a new floating-dock to be made, at the expence of 20,000l. It is situated near the Hot-well-road; its gates will admit a 64 gun vessel, and it will contain 40 sail of shipping. Here also are dry and wet docks, for repairing and building ships. A scheme has long been in contemplation to dam up the water, and keep the vessels in the harbour constantly afloat. In 1803, an act of Parliament was obtained for the purpose, a plan was adopted, and this great work is now executing with all possible expedition. When completed, the port will be capable of holding 1000 sail of shipping, which convenience must, eventually, be of great advantage to the city. The plan is to dam up to a certain height the whole of the present bed of the Avon and Frome, and to make a new channel for the river through Redcliffe meads. Three hundred thousand pounds are already subscribed, and three years given to accomplish the design. From what has already been done, it is conjectured that the expenditure will not exceed the estimate; and if workmen can be obtained, it is presumed that it will be finished within the assigned period. By this plan, ships will not only be kept afloat at the quays, but may enter the locks, and go to sea at neap tides, which will be a wonderful saving in time and expence; and a navigation will be opened up the Avon, as high as the town of Keynsham, in one level: the money to be raised by duties and taxes, bearing an interest of 4 per cent. and not exceeding 8 per cent. The interest is to be raised by a tax on houses in the city, of

one shilling per pound rent, and a port-duty on all goods and merchandize imported. The tax on houses is considered too partial to be just; and the duties on articles imported may probably act as a considerable prohibition on foreign vessels frequenting the port. Time alone, however, must discover the policy or impolicy of thus raising the sum necessary for its accomplishment. The trade of this port has been ever fluctuating from the time of Henry II. 1157, (when William of Malmesbury makes such honourable mention of it) to the present time. Every vessel of above 60 tons burthen pays a certain wharfage; and from the water-bailiffs' returns, it appears that, in 1745, it amounted to 918l. 18s. 7½d: in 1775, to upwards of 2000l. In 1742, the privateers fitted out from Bristol, according to Barret, exceeded in tonnage, number of guns and men, the whole royal navy of Great Britain. In 1769, there were entered inward at the Custom-house 427 foreign ships, exclusive of Londoners, Coasters, &c.

In 1787 the entry at the custom house was as follows:

Ships. Tons.		Ships. Tons.	
Entered inwards—Brit.	416 48,125	Foreign, 69	11,112
Entered outwards—Brit.	382 46,729	Foreign, 66	10,445

The following is a list of ships and vessels belonging to this port in 1787:

Foreign Trade.				Coasters.				Fishing Vessels, &c.			
ships.	Tons.	Men.	½ lps.	ships.	Tons.	Men.	½ lps.	ships.	Tons.	Men.	½ lps.
328	53,491	3971	30	3078	142	7	340	30			

After this period the trade increased considerably; and another computation states, that in 1788, 34 ships were employed to Jamaica, 38 to the Leeward islands, 37 to Africa, 33 to Newfoundland, 50 to North America, and 200 between Bristol, Ireland, France, Spain, London, &c. amounting to 1392; besides 103 trows from 50 to 130 tons burthen, employed in the Severn and Wye trade. But the commerce of Bristol received a severe check during the last war; and the present paralyzes the spirit of adventure, and the hand of industry. Should peace quickly return, and the port be finished, there can be little doubt but this place will become more flourishing than ever.

Besides the foreign trade, Bristol has many very considerable manufactures; and the cheapness of fuel, with the ready conveyance to a market, renders this an advantageous place for carrying on various trades. The brass rollery business was begun here about 1704. The manufactory of zinc out of calamine stone, and the ore of zinc called black Jack, was established at Bristol in 1743, for which Mr. Champion obtained a patent. Mr. Emerson at Hanham established works for making brass, by exposing copper to the fumes of calamine, and obtained the finest brass in the world. Vide Watson's Chemistry.

The glass houses of Bristol are not only numerous, but great quantities of different glass articles, and bottles, are annually made here. This trade is increasing, and it is said that more glass is manufactured at Bristol than at any other place in England. Many large iron founderies are also established here, and a steam-engine factory is erected for boring cannon; smelting lead, and making of white and red lead, are among the manufactories of this city.

There are 20 sugar-houses for the refining and manufacture of sugars; several large distilleries, which help to supply London; and the exportation to foreign parts is very considerable. The manufacture of soap has long been an article of great trade here; for, in 1523, it supplied London with the best gray speckled soap at 1d. per pound; but it is now 1s. Large quantities are still sent to London,

to most parts of the kingdom, and to America. This place was, at an early period, noted for its woollen trade. In 1339, we find from Rymer, that the cloth manufacture was removed from Flanders, when Bristol was appointed a principal staple of wool, and many looms were set up for weaving woollen cloths. In Henry VIIIth's reign, it was full of clothiers, weavers, and tuckers; and the magistrates gave great encouragement to set up the Colchester rug manufactory, and many sums have at times been left to the corporation in trust for the use of young clothiers. This trade is not entirely taken away, as some woollen stuffs, serges, &c. are still made. The manufacture of silk fringes, sail cloth, cottons, morocco-leather, &c. must not be omitted. Several potteries also now rival those of Staffordshire.

Military History, Castle, &c.—It is highly probable, that so conspicuous and important a place early partook of the disasters arising from the internal commotions of this kingdom, and the evils arising from foreign invasion. But history is silent, the records being lost till 915, when Stow says, a great navy of Danes sailed up channel and infested the western coasts, landed in divers places, and took great plunder; at which time Bristol suffered from the marauding enemy. King Edward son of Alfred, 911, according to the Saxon annals, sent his army out of Mercia, and met them in Wessex, where he fought and routed them. The battle was decisive, and the Danes were then subject to the Saxon monarch. Edward went on to build towns and castles; and amongst others he built that of Bristol, on the Mercian side of the river Avon. Camden, therefore, was evidently mistaken when he asserts that Robert Rufus, natural son of Henry I. was the founder of the castle of Bristol. Turgot mentions it as the work of Edward in 915, and says, it was "the goodliest of five built on the banks of Avon;" and in 1088, it is mentioned by Roger Hoveden as "Castrum fortissimum;" and if it were so strong 20 years after the conquest, there cannot be a doubt, but it previously existed as a fortress for the defence of the city. Another decisive proof of Camden's error is, that the castle was held by Godfrey bishop of Constance, and Robert de Mowbray earl of Northumberland, in a rebellion against king William Rufus in 1088; before king Henry I. earl Robert's father, was at man's estate. This earl, though not the founder, certainly rebuilt some parts, repaired others, and erected a palace and other offices. He also built a magnificent tower, scarcely equalled at that time in England, and encompassed the whole with strong walls. Leland informs us, that Robert built part of it, and that "the dungeon tower was made of stone brought out of Normandy by the redde earl of Gloucester." It was not till 1130, that earl Robert began to rebuild and improve the castle; which, excluding the out-works, was 450 feet from east to west, and 300 feet from north to south. There were in it two great courts, many towers, a church, and a magnificent chapel. The king had also a palace within the walls. The principal buildings stood upon an area, covering 3½ acres of ground, exclusive of courts, yards, and other accommodations for the officers and the garrison. Leland informs us, that the great tower stood in the north west part of the castle; and in his time, about 26th of Henry VIII., the whole was in a decayed state, and tending fast to ruin. In the reign of John, the castle was annexed to the crown; and here that monarch cruelly confined the princess Eleanor, (called the damsel of Brittany,) who, after forty years miserable confinement, died here in 1241. In the barons wars, during the reign of Henry III., prince Edward his son supplied the castle with provisions, and fined the

townsmen 1000*l.* for not assisting him with supplies. The latter besieged him in the castle, and the prince fled to Windsor, where he was soon forced to accept terms at the hands of the barons. When the duke of Lancaster opposed Richard II. the inhabitants of Bristol threw open their gates to the duke's forces, who stormed and took the castle, in which many of the king's friends had taken refuge. The inhabitants of Bristol sided with the earl of Richmond, afterwards Henry VII. at which time Giles lord d'Aubenev held the castle. During the reformation, tumults broke out in the west; and at Bristol, the castle walls, and gates of the city were repaired and mounted with cannon; but by the prudent conduct of Mr. William Chester, the discontents were soon appeased, and a general pardon was procured for the delinquents. In the years 1545 and 1553, a mint was established in the castle; and the church plate, seized by the commissioners, was here coined. By a petition to king Charles I., 1629, the king granted the castle and its appurtenances to the mayor and corporation of Bristol, and made it a part of that county and city; and in 1631, it was sold to the mayor and burgesses for 959*l.* In the commencement of the war, between the king and his parliament, the castle was repaired and garrisoned by the parliament-army under the government of Col. Nath. Fiennes. This was considered a place of the greatest consequence, and served to awe all the western counties, having accommodations for a large army. The king, therefore was very desirous of obtaining possession; a plot was formed by Yeamans and Bouchier, to deliver it up to the king's forces; but this being discovered, prince Rupert, at the head of a considerable army, besieged it; but fearing the length of a blockade, he determined to take it by storm, which he quickly effected. But the place was thus dearly bought, for the king lost most of his valuable officers, and more than 500 of his best troops. It was thought of so much consequence, that a public thanksgiving was ordered for the success of his majesty's arms. The citizens subscribed 1400*l.* to prevent the plunder of the soldiery; and orders were consequently given for death to be the penalty of plunder. Bristol was ordered to pay 50,000*l.* in money, and clothe and equip 1500 of the king's soldiers. At the battle of Naseby, prince Rupert repaired to Bristol, which he found supplied with men, provisions, and ammunition, so that he wrote to the king, assuring him he was able to

sustain a four months' siege. This revived the hopes of the king's party; and it was thought that the prince would make a vigorous and desperate defence; but, to the surprise of all, he made but a very feeble and short resistance.

This unexpected and disastrous event damped the royal cause, which from that day rapidly declined; and certainly the capitulation of this grand station hastened the fatal catastrophe of the king's submission, and subsequent decapitation. After Oliver Cromwell was proclaimed protector, he issued orders for the demolition of the castle of Bristol. The dismantling was begun in 1665, and the whole was razed to the ground. Scarcely any vestiges are now remaining. Thus this fortress, deemed impregnable in former ages, and which has made such a distinguished figure on the page of history, the subject of so much negotiation, and so much contention, was destroyed after having weathered the storms of seven centuries. The inhabitants, previous to this period, appear to have always been in opposition to the reigning princes, but subsequently, however, the reverse appears the case. In the duke of Monmouth's rebellion, they espoused the cause of king James. During the rebellion, in the reign of George I., and especially in 1745, they were decidedly for the house of Hanover; and in the present day their exertions in defence of the nation are too well known to need a comment.

Such are the most material places, objects and events, connected with the city of Bristol. We may further state that its buildings cover an area of about 1000 acres of ground, and the suburbs above 500 more. With the appendages it contains 600 streets, squares, lanes, courts, &c. in which are erected 47 churches and chapels. Here are 5 hotels, 50 inns and taverns, 7 banking houses, and 4 prisons. It is the chief city, quay, and mart of the western parts of the kingdom, and is classed among the principal cities of Europe.

Bristol is the birth-place of many distinguished literary and public characters, the memoirs of whom will be introduced under their respective heads. We shall therefore only mention the names of the principal: Thomas Chatterton, poet, sir William Draper, William of Worcester, William Cannynge, Edward Colston, Ann Yearley, Mary Robertson. For an account of the Hotwells, Clifton, St. Vincent's rocks, and many places in the vicinity, see CLIFTON. Barret's History of Bristol, 4to. 1789.

Britain

BRITAIN, GREAT, the most considerable island of Europe, comprehending the two kingdoms of England and Scotland, with the principality of Wales, and extending from Lizard point, N. lat. 50° nearly to Dungsby-head in N. lat. $58^{\circ} 30'$ nearly. Accordingly, its length is about 590 miles. Its greatest breadth from the Land's End, in W. long. $5^{\circ} 45'$ to the North Foreland, in E. long. $1^{\circ} 17'$ is about 488 miles. Its form, however, is somewhat triangular; as it has three promontories, projecting in different directions, viz. the Land's End, in Cornwall, towards the west; the North Foreland, in Kent, towards the east; and Dungsby-head, in Caithness, towards the north; and the circuit of its three sides, allowing for the windings of the coast, contains, by a general estimate, about 1800 miles. But if Great Britain were considered as a perfect triangle, the length of its three sides would measure about 1520 British miles. It is bounded on the north by the Northern Ocean, on the west by the Atlantic and the Irish Sea, which separates it from Ireland, on the south by the British Channel, which divides it from France, and on the east, towards Germany, by the North Sea and German Ocean. Some have supposed, that Great Britain was, in times of very remote antiquity, united with the continent. The entire separation of Great Britain from the continent must have happened, according to the conjectures of Mr. Kirwan, (*Irish Transact.* vol. vi. p. 301.) long after the deluge, and that of Ireland from Great Britain at a still later period; for wolves and bears were anciently found in both, and these must have passed from the continent into Britain, and hence into Ireland, as their importation cannot be suspected. The divulsive force that separated Britain from Germany seems, according to this writer, to have been directed from north to south, but gradually weakened in its progress. Hence that island is sharpened to the northward; but the impression must have been considerably enfeebled by the opposition of the granitic mountains that form the Shetland and Orkney isles. The broken structure of the calcareous or argillaceous and arenaceous materials of the more southern parts presented less resistance, were more easily preyed upon, and gave way to what is now called the German Ocean, while these materials themselves were spread over Westphalia, &c. or formed the subsoil of Flanders, Holland, and the sand-banks on its coast. The rupture of the isthmus that joined Calais and Dover was probably effected by an earthquake at a later period, and gradually widened by tides and currents. Ireland was protected by Scotland from the violence of the northern shock; and hence its separation from Scotland appears to have been late and gradual. That from England was probably diluvial, and effected by a southern shock. These changes, says this writer, happened at least 3600 years ago. But to return from this digression.

The fertility and pleasantness of Great Britain gave occasion to imagine that these were the fortunate islands, described by the poets, where the face of nature exhibited a

perpetual spring. In former times this was the granary of the western empire: from hence was transported every year an immense quantity of corn for the supply of the army on the frontiers of Germany. As to the history of its more early state, its population, fertility, and a variety of other circumstances relating to it, we refer to the next article.

The climate of Great Britain is, perhaps, more variable than that of any other country on the globe; and this circumstance has been ascribed to the opposition between the vapours of the Atlantic Ocean, and the drying winds from the eastern continent. The western coasts are subject to frequent rains; and the eastern part of Scotland has a clearer and drier temperature than that of England. The humidity of the climate, whilst it invests the delicious vales and meadows with a verdure unknown to any other region, injures the health of the inhabitants, by occasioning colds and catarrhs, which too frequently terminate in consumptions, that are fatal to many in the prime of youth. Besides, the moist and foggy climate conspires, with the excessive use of gross animal food, to produce that melancholy, which foreigners have considered as a national characteristic of the country. To the mutability of the climate we may reasonably ascribe the precariousness of the seasons. To this purpose it has been observed by some judicious persons, that since the year 1775, a considerable change has taken place, with regard to the temperature of the year, both in Great Britain and Ireland. The winters have been, in general, more moist and mild, and the summers have been more humid and more cold, than the average of preceding years. With us the year might not improperly be divided into eight months of winter and four of summer. The spring dawns in April, which is commonly a mild month, but eastern winds prevail in May, and check the efforts of reviving nature, and disappoint the promise of the year. June, July, August, and September, are usually warm summer months, with occasional frosty nights even in August, and cold east wind; and some summers have of late years been chilled by constant rain. Our winter commences with the beginning of October, which, however, is often a mild and pleasant month; severe frost does not commonly occur till Christmas. November is the most gloomy month of the year; and allowed, generally, to be the most unsettled month, interspersed with dry frost, cold rains, and strong winds, with storms of hail and sleet. But all observations of this kind must be considered as general in their nature; and counteracted by different situations with regard to latitude, and by a variety of local circumstances.

The population of Great Britain has been variously estimated; some reckoning it at 7,000,000, and others at more than 12,000,000. But in the year 1800 an act was passed, (41 Geo. III.) "for taking an account of the population of Great Britain, and of the increase or diminution thereof." From an abstract of the returns made to parliament, in consequence of this act, the following result was deduced:

SUMMARY of ENUMERATION.

	HOUSES.			PERSONS.		
	Inhabited.	By how many families occupied.	Uninhabited.	Males.	Females.	Total.
England - - - -	1,472,870	1,787,520	53,965	3,987,935	4,343,499	3,331,434
Wales - - - -	108,053	118,303	3,511	257,178	284,368	541,546
Scotland - - - -	294,553	364,079	9,537	734,581	864,487	1,599,068
Army, including militia -	- - -	- - -	- - -	198,351	- - -	198,351
Navy, including marines -	- - -	- - -	- - -	126,279	- - -	126,279
Seamen, in registered shipping -	- - -	- - -	- - -	144,558	- - -	144,558
Convicts, on board the hulks -	- - -	- - -	- - -	1,410	- - -	1,410
Totals	1,875,476	2,269,902	67,014	5,150,292	5,492,354	10,942,646

On this enumeration it is observed, that the total population of Great Britain probably exceeds the number of persons specified in the above summary, in as much as from some parishes no returns were received. From the number of houses in Ireland, nearly ascertained by the collection of a hearth-money tax, it has been computed, that the population of that part of the united kingdom somewhat exceeds four millions of persons. It should also be observed, that the islands of Guernsey, Jersey, Alderney, and Sark, the Scilly islands, and the Isle of Man, were not comprised in this enumeration; and that the total population of these islands has been usually estimated at about 80,000 persons. On these considerations, with a very moderate allowance for omissions in the returns, the total population of the united kingdom of Great Britain and Ireland amounts to *fifteen millions one hundred thousand* persons; and besides these, its eastern and western possessions and colonies contain many natives of the British isles. On a more enlarged survey of these colonies and settlements, we may consider their inhabitants either as subjects of Great Britain, or as augmenting its importance by their intimate connection with it. The most important of these are now in Asia; and in Hindostan, the nations subject to Great Britain cannot be now calculated at less than 40 millions. The acquisition of the Dutch settlements, the colony of New Holland, and more minute stations, must also be taken into the account. In America, and what is called the West Indies, Canada, Nova Scotia, Newfoundland, and the more northern settlements, with Jamaica, and the other islands, may, perhaps, contain a million. In Africa, the settlements at the Cape of Good Hope, the islands of St. Helena and at Sierra Leone, present an insignificant number; and Gibraltar is to be regarded merely as a military station. However, if we compute the North American states, detached from the mother country, at a population of five millions, the united kingdom of Great Britain and Ireland at 15 millions, and our colonies and settlements at only two millions, we shall find in the various countries of the globe an increasing population of 22 millions, diffusing the English language and manners to a vast extent, and contributing in one way or other to the wealth, power, greatness, and prosperity of Great Britain.

From the above table it appears, that the enumeration of 1801 amounts to 8,872,980 persons for England and Wales; and to this number an appropriate share of soldiers and marines is to be added. These appear to have been 469,188;

and if, exclusive of them, the total population of the British isles is 14,630,817, (15,100,000—469,188) about a thirtieth part may be added to the inhabitants in order to ascertain the population of any distinct part. Accordingly, in the following table, the existing population of England and Wales is taken at 9,168,000; and the population attributed to the other years, is obtained by the rule of proportion, thus: if 255,426 baptisms (the average medium of the last five years, deduced from the returns of parish registers,) were produced from a population of 9,168,000, from what population were 152,540 (the baptisms of 1700, given in the same returns) produced?

TABLE of Population throughout the last Century.

ENGLAND and WALES.	
In the Year.	Population.
1700 - - -	5,475,000
1710 - - -	5,240,000
1720 - - -	5,565,000
1730 - - -	5,796,000
1740 - - -	6,064,000
1750 - - -	6,467,000
1760 - - -	6,736,000
1770 - - -	7,428,000
1780 - - -	7,933,000
1785 - - -	8,016,000
1790 - - -	8,675,000
1795 - - -	9,055,000
1801 - - -	9,168,000

Upon a view of this table it may be observed, that although the beginning of the century exhibits a decreasing population, the lost number had been regained in 1720; and since that time a continual, though irregular, increase is manifest. It also appears, that the population of England and Wales, in 1801, compared with that of the beginning of the last century, is as 1,000 to 597, or nearly as ten to six.

The following table for Scotland is formed in the same manner; but being founded on a collection of no more than 99 parish registers, from different parts of the country, it is of much less authority. These parishes contain less than a seventh of the whole population. In Scotland there are in all about 900 parishes.

TABLE of Population throughout the last Century.

SCOTLAND.	
In the Year	Population.
1700 - - -	1,048,000
1710 - - -	1,270,000
1720 - - -	1,390,000
1730 - - -	1,309,000
1740 - - -	1,222,000
1750 - - -	1,403,000
1760 - - -	1,363,000
1770 - - -	1,434,000
1780 - - -	1,458,000
1785 - - -	1,475,000
1790 - - -	1,567,000
1795 - - -	1,669,000
1801 - - -	1,652,370

The population of Scotland, in 1801, compared with that of the beginning of the last century, appears to be as 1000 to 634, or nearly as 10 to 6½, which, as the 99 parish registers were received from the manufacturing parts of Scotland, gives too high a statement of the increase of population.

In the year 1695 a poll-tax was levied in Ireland; and on this occasion it was calculated, that the number of inhabitants was 1,034,000; but the usual evasion of taxation may be supposed to have considerably lessened the real number. About the year 1795, Ireland contained, at least, 4,000,000, and since that time the number has not increased. However, it may not be very erroneous to estimate the population of Ireland at 1,500,000 in the year 1700, and at 4,000,000 in the year 1801. If this be granted, the population belonging to all the British isles has increased during the last century from 8,100,000 to 15,100,000.

Of the population of Great Britain, the army has, of late years, engrossed a considerable share. It consists of regulars, in cavalry, and infantry, and the militia, exclusive of artillery and engineers. The volunteer corps in Great Britain and Ireland amounted in December, 1803, to 430,000; and on the 1st of January, 1805, the secretary of war made the following return of the state of the British forces at home, and on foreign stations, viz. 21,223 of cavalry, including 1,088 horse artillery; 8,559 of artillery; 124,878 of infantry, including 20,747 men for limited service, and 21,208 men belonging to foreign and provincial corps in British pay; and 89,809 of militia: so that the whole British force, in regulars, militia, and volunteers, amounts to 674,469 men. To these we may add the royal regiment of artillery, the horse brigade, the brigade of gunners and drivers, and companies of foreign artillery, amounting on the 1st of January, 1805, to 16,670; and the corps of royal artillery, artificers and labourers, including, at the same period, 704 men.

But the great rampart and supreme glory of Great Britain consist in her navy, in size, strength, and number of ships, far exceeding any example on record. In 1805, the total of ships in commission amounted to 684, consisting of 111 of the line, 19 fifties to forty-fours, 150 frigates, and 204 ships of various kinds; besides several repairing, in ordinary, and building: amounting in the whole to 895. For this immense fleet, the number of seamen, annually voted, amounts from a hundred to a hundred and twenty thousand; a number which no other country ancient or modern could have supplied. To support the expenditure occasioned by the army and navy of Great Britain, to defray the other charges of government, and also to discharge the interest of the national debt, a very large

sum is raised by a variety of taxes, in aid of the revenue, arising from the excise and customs. The ability of the country for bearing the burden which its exigencies impose upon it, consists in the produce of its land and manufactures, and in the circulation of property, occasioned by its domestic trade and foreign commerce. These sources of national wealth have been improved to an astonishing degree in the course of the last century and a half. Availing ourselves of the estimate of the national wealth of Great Britain, furnished by Mr. Grellier, an ingenious writer, in one of our periodical publications (Monthly Magazine, vol. x.) we shall subjoin the following statement of its vast increase during the period above mentioned. In 1664, sir William Petty estimated the wealth of England at the sum of two hundred and fifty millions. His computation is subjoined.

Value of the land; being 24 millions of acres, yielding 8 millions per annum rent, worth at 18 years purchase	£. 144,000,000
Houses; reckoning those within the bills of mortality, equal in value to one-third of the whole	30,000,000
Shipping; 500,000 tons, at 6l. per ton, including rigging, ordnance, &c.	3,000,000
Stock of cattle on the 24 millions of acres and the waste belonging to them, including parks, fisheries, warrens, &c.	36,000,000
Gold and silver coin, scarce	6,000,000
Wares, merchandize, plate, furniture	31,000,000
	£. 250,000,000

But since the time when this computation was made, a great difference in the value of money has taken place, which difference appears from the table of sir George Shuckburgh Evelyn, in the Philos. Transf. for 1798, part 1, page 177, to be in the proportion of about 5 to 14; and, therefore, the total wealth of England and Wales, in 1664, would have amounted to 700,000,000l. according to the present value of money.

The value of land has progressively increased, in consequence of improvements in cultivation, and the increased consumption of its produce, from 18 years' purchase, at which sir William Petty states it, to from 28 to 30 years' purchase. The whole landed rental of England and Wales, and the Low-lands of Scotland, was stated by this writer at about 9 millions; and if he had included the High-lands of Scotland, it is reasonable to suppose that he would not have made the whole rental of the island more than 9,500,000l. G. King and Dr. Davenant, in the reign of queen Anne, stated the rental of England and Wales at 14,000,000l.; about 25 years ago, it was generally reckoned at 20,000,000l.; but at present it considerably exceeds that sum. The cultivated land appears, from the statement of Mr. Middleton, in his "View of the Agriculture of the County of Middlesex," to be 39,027,000 acres, and the commons and waste-lands to be 7,889,000 acres; and, therefore, the total of acres in England and Wales amounts to 46,916,000 acres. If, therefore, we consider the commons and waste lands as equal in annual value to only one million of cultivated acres, the whole may be taken at 40 millions: and taking the average rent, which, at 15s. per acre, appears to be a moderate computation, at a tenth less, the rental amounts to 27,000,000l. and the value at 28 years' purchase to 756,000,000l. The number of cultivated acres in Scotland is upwards of 12 millions, and of uncultivated acres upwards of 14 millions, which, being of little use, may be wholly excluded; and the cultivated part, being rated at an average of 10s. per acre, yields the sum of 6,000,000l.

per annum: and the total rental of Great Britain will be 33,000,000*l.* and the value of the land, at 30 years' purchase, be 990,000,000*l.* Other writers have endeavoured to prove, (see Beche's "Observations on the Produce of the Income Tax,") that in the whole extent of England and Wales there are no more than 38,500,000 acres of land; and that Scotland, with its adjacent islands, contains about 21 million of acres. It is not so easy to ascertain the value of the houses as it is to determine the value of the land; but the following statement of their rent, founded on the numbers returned as chargeable and excused to the window duties, in England and Wales, in 1781, will not be thought too high:

	Rent.
Number of cottages 284,459, at 20 <i>s.</i> } per annum - - - - - }	£ 284,459
Number of houses under 10 windows, } 497,801, at 5 <i>l.</i> per annum - - - }	2,489,005
Number of houses under 21 windows, } 171,177, at 15 <i>l.</i> per annum - - - }	2,567,655
Number of houses, above 20 windows, } 52,373, at 40 <i>l.</i> per annum - - - }	2,094,920
Total - - - - -	£ 7,437,039

The total rent, at 20 years' purchase, makes 148,720,780*l.* and including Scotland at less than a sixth of England and Wales, the whole will amount to 170,000,000*l.*

In order to form an idea of the value of cattle and farming stock, on the land, we may consider the black cattle and calves, sheep and lambs, swine, pigs, and poultry, annually consumed in London as worth 6,000,000*l.* which cannot be more than a seventh part of the whole consumption, amounting therefore in value to 42,000,000*l.*; but the whole number of cattle existing must be more than double the quantity brought to market; so that, including horses, affs, cows kept for milk, and oxen employed in agriculture, the whole value of the cattle cannot be less than 90,000,000*l.*

Taking the annual consumption of grain of all sorts at 14,000,000 quarters, which is probably below the truth, it may be presumed, that in general there is at least three or four months' supply on hand, which, at only 3*s.* per quarter, will amount to at least 6,125,000*l.* The value of hay and straw, and all kinds of fodder and of all implements of husbandry, cannot be less than five or six millions, and with the former sum will make about 12,000,000*l.* The total value of cattle and farming stock is therefore 102,000,000*l.*; and if it be estimated as equal in value to only three times the yearly rent, it will amount to nearly this sum.

The value of the shipping belonging to Great Britain may be more accurately ascertained: for it appears that, in 1794, the tonnage of the vessels in the merchants' service was 1,589,152 tons; but taking it at 1,500,000*l.* at 8*l.* per ton, it makes 12,000,000*l.* and this is without doubt below the real value. In the year ending the 5th of January, 1804, the number of British ships entered inwards was 11,396; their tonnage 1,614,365; and the number of foreign ships 4,252, and their tonnage 638,034; the number of British ships cleared outwards, was 3,662, and their tonnage 574,542; and the number of foreign ships 3,662, and their tonnage 574,542. The shipping of the navy may perhaps be estimated at 4,000,000*l.* making, with the former sum, 16,000,000*l.* to which some addition should be made for the value of the small craft employed on our rivers and canals.

The quantity of money in the country has, at different times, been a subject of dispute, and has never been determined with precision. However, by the recoinage in 1773, 1774, and 1776, it was found, that the value of the light gold delivered into the bank amounted to 15,563,593*l.*; and it was generally admitted that somewhat more than two

millions of heavy guineas remained out in circulation, which with the silver and copper coin, made the whole, at that time, about 20 millions; at which sum Mr. Chalmers estimated it in the year 1786. Mr. Grellier estimates it at about 25 millions.

Of the value of the merchandize and manufactures usually in the hands of the merchants, wholesale dealers, shop-keepers, and manufacturers, it is very difficult to form a satisfactory idea. The total amount of the exports in 1797 was 28,917,000*l.* and of imports 21,013,000*l.* according to the custom-house accounts; but these accounts being considerably below the true value, if we take the whole as rated only 60 per cent. under the value in 1800, the annual amount of foreign trade estimated for that period, will be 79,880,000*l.* to which some addition should be made for smuggled goods. Mr. Pitt, in 1799, computed the imports at 25,000,000*l.* and the exports at more than 33,000,000*l.*; and in Feb. 1801, the foreign exports at 17,000,000*l.* and the domestic at 20,000,000*l.*, amounting to a total of 37,000,000*l.* The official value of all imports on an average of six years, ending the 5th of January, 1804, was 29,490,945*l.*; and the official value of British manufactures exported, on the same average to the same time, was 23,834,340*l.*; and real value 40,100,870*l.*; and the official value of foreign merchandize exported, on the same average, to the same time, was 15,323,500*l.*; and the real value 9,323,257*l.* It was the opinion of a numerous meeting of merchants in March, 1797, that there is always, at the least, two months' supply of export and import merchandize in the custody of the merchants and traders, which, according to the above total of 79,880,000*l.* will amount to 13,314,666*l.* to which some addition should be made for property in the hands of foreign merchants. But the value of goods in the hands of manufacturers and retail traders far exceeds this sum. The official value of British manufactures exported in 1798 was 19,771,510*l.*; but this being at least 71 per cent. below the real value, we may take the actual value, on an average of two years, at 31,356,793*l.*, which, it is presumed, cannot be more than a third of the whole produce of our manufactures; and accordingly, this will amount to 94,070,379*l.* If we deduct 5,000,000*l.* for that small part which is supposed to be in the hands of the merchants, the remainder will be 89,070,379*l.*; and of this it is probable that there is much more than three months' supply in the hands of the manufacturers and retail traders, which estimated in this proportion, amounts to 22,267,594*l.*

As to the value of that part of the property of individuals which consists in household furniture, wearing apparel, provisions, fuel, carriages, &c. &c. we can recur only to conjecture; but it may be thought not to be over-rated at three times the yearly rent of the houses which contain it, or 26,026,000*l.* in the whole of Great Britain.

The following summary will exhibit the results of the above estimates:

Value of the land of Great Britain	£ 990,000,000
Houses - - - - -	170,000,000
Cattle, and all kinds of farming stock -	102,000,000
Shipping, navy, and merchant ships	16,000,000
Money - - - - -	25,000,000
Goods in hands of merchants and whole- sale dealers - - - - - }	13,314,000
Goods in hands of manufacturers and retail-traders - - - - - }	22,267,000
Furniture, apparel, &c. - - - - -	26,026,000
Total	£ 1,364,607,000

From the above statement it appears that, since the year 1664, there has been an average gain of upwards of four millions per annum, of which a very considerable part has been derived, directly or indirectly, from foreign commerce. The great increase of the annual income affords a further proof that there must have been such an accumulating surplus. Sir W. Petty (Pol. Arith. p. 123.) supposed the income derived from land to be 8,000,000*l.* the profits of personal estates 8,000,000*l.* and the profits of all kinds of labour 26,000,000, making together 42,000,000*l.* Mr. G. King estimated the whole income at 43,500,000*l.* Dr. Davenant, in 1701, states the income derived from land at 10,000,000*l.* the profits of trade at 6,000,000*l.* and those of sciences, arts, labour, industry, manufactures, retailing foreign goods, and buying and selling home commodities, at 33,000,000*l.* making in the whole 49,000,000*l.* These accounts are exclusive of Scotland; but after making a sufficient addition for this country, it will appear that there has been a considerable increase of the general income. Sir John Sinclair, in his "Hints addressed to the Public," in 1783, observed, that the income of the country arising from lands, commerce, and manufactures, was commonly calculated at 100,000,000*l.* which he inclined to think a low valuation; and, without doubt, the profit derived of late years from each of these sources has considerably increased. It is not easy to form a very precise estimate of the national income; but the following statement is presumed to be not very inaccurate:

From rent of lands	£. 33,000,000
—ditto of houses	8,500,000
Profits of farming, or the occupation of the land	6,120,000
Income of labourers in agriculture	15,000,000
Profits of mines, collieries, and inland navigations	2,000,000
Profits of shipping in merchants' service, and small craft	1,000,000
Income of stock-holders	15,500,000
From mortgages, and other money lent on private securities	3,000,000
Profits of foreign trade	11,250,000
Ditto of manufactures	14,100,000
Pay of the army and navy, and seamen in merchants' service	4,500,000
Income of the clergy of all descriptions	2,200,000
Income of the judges, and all subordinate officers of the law	1,800,000
Professors, school-masters, tutors, &c.	600,000
Retail trades, not immediately connected with foreign trade or any manufacture	8,000,000
Various other professions and employments	2,000,000
Male and female servants	2,000,000
Total	£. 130,570,000

If the total expenditure be estimated at 125,860,000*l.*, which has been deduced from a minute, and, perhaps, as accurate a statement of particulars as the subject, admitting of various conjectures and presumptions, allows, the difference between this expenditure and the general income shews the annual gain of the country, or the sum applicable to the extension of commerce, the reservation of a greater quantity of foreign articles, the increase of shipping and buildings, agricultural or mechanical improvements, or other augmentations of the general stock.

On introducing the income-tax, Mr. Pitt, chancellor of the exchequer, gave the following estimate of the annual income of Great Britain:

The land rental, after deducting one-fifth	£. 10,000,000
The tenants' rental of land, deducting two-thirds of the rack-rent	6,000,000
The amount of tythes, deducting one-fifth	4,000,000
The produce of mines, canal navigations, &c. deducting one-fifth	3,000,000
The rental of houses, deducting one-fifth	5,000,000
The profits of professions	2,000,000
The rental of Scotland, taking it at one-eighth of that of England	5,000,000
The income of persons resident in Great Britain, drawn from possessions beyond the seas	5,000,000
The amount of annuities from the public funds, after deducting one-fifth for exemptions and modifications	12,000,000
The profits on the capital, employed in our foreign commerce	12,000,000
The profits on the capital employed in domestic trade, and the profits of skill and industry	28,000,000
Total	£. 102,000,000

As one of the principal sources of the wealth of Great Britain consists in its manufactures, it may not be improper to give a brief statement of them; reserving a more copious detail for other articles in this dictionary, under which they will separately occur. The woollen manufacture deserves to be first mentioned, because it is the most ancient, and, in a variety of respects, the most important staple of the country. In an examination of the principal woollen manufacturers by a committee of the house of commons not long ago, the quantity of wool grown in this country was estimated at 600,000 packs of 240*lbs.* each, which, valued at 1*l.* per pack, amount to 600,000*l.*: and though the increase of value of manufactured wool is various, and depends on its quality, yet it was stated, that the total value of the wool manufacture in this country amounts to 19,800,000*l.* But the calculation supposes, that the number of sheep, in 1791, was 28,800,000, which exceeded the truth at that time, and much more since that period; and it was formed upon an unusually high price of wool. But the estimate will be much less objectionable, if it be formed on 500,000 packs at 1*l.* 10*s.* per pack, and thus the value of the wool will be 5,250,000*l.*, and its manufactured value will be 15,750,000*l.* The average value of woollen goods exported for 1797, 1798, and 1799, is 6,104,211*l.* which, as the custom-house values of goods exported are much below their real value, requires an addition of about 25 per cent. and thus it becomes 7,630,263*l.* The value of goods retained for home consumption will be nearly equal to that of such as are exported; and, therefore, the whole value of the manufacture appears to be about 15,260,000*l.* and may be taken, at a medium, between this sum and that before stated, at 15,500,000*l.* Deducting 10 per cent. on the cost of the goods, for the profits of the manufacturer, with interest of his capital, there will remain 14,090,000*l.* for the cost of materials and wages of labour: and as the value of the wool is about 5,250,000*l.*; the amount of workmanship, or the wages of all the persons employed in this manufacture, is 8,840,000*l.*; and the whole number of persons employed, averaging their wages at 8*s.* each per week, does not exceed 425,043.

The value of the leather manufacture may be stated at 10,500,000*l.* from which deducting 954,545*l.* for the profits of the capital, and 3,500,000*l.* for the cost of the raw

article, there will remain 6,045,455*l.* for the wages of persons employed in it, which, allowing to each 25*l.* a year at an average, makes the number employed 241,818.

The cotton manufacture was formerly inconsiderable, in comparison with its present state. The total quantity of cotton wool imported into England, on an average of five years, ending with 1705, was 1,170,881*lbs.*; and so late as the year 1781, it amounted to only 5,101,920*lbs.* But this manufacture was so much extended, that before the commencement of the last war the consumption of cotton wool amounted to upwards of 30,000,000*lbs.* per annum. During the years 1796, 1797, 1798, and 1799, the annual import, at an average, was 30,431,000*lbs.*; the value of which, when manufactured, cannot be less than 9,500,000*l.*; and if we deduct from this sum 863,636*l.* for profits of capital, at 10 per cent. and 3,804,250*l.* for cost of the raw material at 2*s.* 6*d.* per pound, there will remain 4,832,114*l.* for wages, which, divided at the rate of 15*l.* per annum for each person, on account of the number of women and children employed, makes the whole number 322,140 persons.

The silk manufacture has of late years experienced little fluctuation; the average of raw and thrown silk imported for three years preceding the 5th of January, 1797, was 883,438*lbs.*; and the usual quantity cannot be stated at less than 900,000*lbs.* the value of which, when manufactured, is about 2,700,000*l.* The cost of the silk, averaging that of the raw and thrown at 28*s.* per pound, amounts to 1,260,000*l.*, and the profits of the manufacturer to 245,454*l.* at the rate of 10 per cent. on the cost when manufactured. The number of persons employed in this manufacture has been stated at 200,000 and upwards; but there is reason, says Mr. Grellier, to believe that it does not exceed 60,000 of all descriptions.

The linen manufacture of Great Britain is chiefly confined to Scotland, though some branches of it are carried on in Manchester and other parts of England. The total quantity of British linen exported during the years 1797, 1798, 1799, was 56,481,000 yards; and if the quantity retained for home consumption is not greater than the export, the value of the whole must be at least 1,600,000*l.*; and that this does not exceed the truth is probable, if the yearly value of the whole manufacture in Great Britain, with the thread and other branches of the flax trade, is stated at 2,000,000*l.*, and the number of persons employed at 60,000.

The hemp manufacture at present exceeds 1,500,000*l.*, but it is less in time of peace; and the number of persons employed is probably not less than 35,000.

The paper manufacture has of late greatly advanced. About 100 years ago, the paper made in this country was almost wholly the coarse wrapping paper, and for a long time the superior kinds were for the most part imported; but the export is now considerable. The annual value of the manufacture, at the present high prices of the article, cannot be less than 900,000*l.*; and the number of persons employed is 30,000.

The glass manufacture has of late very much improved and increased; so that it may now amount to 1,500,000*l.* and the persons employed in it are about 36,000.

The potteries and manufactures of earthen ware and porcelain have rapidly advanced during the present century, in consequence of the improvement they have received, and the introduction of many new and beautiful wares both for our own use and foreign markets. We are particularly indebted to Mr. Wedgwood, "for converting clay into gold." The annual value will probably not be over-rated at 2,000,000*l.*, and the number of persons employed at 45,000.

The iron manufacture is supplied partly by the produce of our own mines, and partly by those of other countries.

With respect to the first it is said, the total produce of pig-iron in Britain does not at present exceed 100,000 tons, and reckoning on an average, that 33 cwt. of crude iron produces one ton of bars, and that the manufacture of malleable iron amounts to 35,000 tons per annum, this branch will require 57,750 tons of crude iron; and the value in bars at 20*l.* a ton is 700,000*l.*; the remaining 42,250 tons, cast into cannon, cylinders, machinery, &c. at 14*l.* a ton, is worth 591,500*l.* The supply of foreign bar iron is chiefly obtained from Russia and Sweden; and the quantity imported, on an average of 12 years, has been 44,135 tons, worth, at 22*l.* per ton, 970,970*l.*, which, together with the former sums, amounts to 2,262,470*l.* Some years ago, the value of the iron manufacture was estimated at 8,700,000*l.*; but if this sum should appear too high, we may include tin and lead, and the value of the whole will probably amount to 10,000,000*l.*, and the number of persons employed to 200,000.

The copper and brass manufactures are now established in this country. Till about the years 1720 or 1730, most of the copper and brass utensils used for culinary and other purposes in this country were imported from Hamburg and Holland, being procured from the manufactories of Germany: and even so late as the years 1745 and 1750, copper tea-kettles, saucepans, and pots of all sizes, were imported in large quantities. But by the persevering industry, capital, and enterprising spirit of our miners and manufacturers, these imports have become totally unnecessary; so that the articles are now all made here, and far better than any other country can produce. The discovery of new copper-mines in Derbyshire and Wales, about the year 1773, contributed to the extension of the manufacture in this country; and it appears to be still increasing, notwithstanding the late great advance in the price of copper. The value of wrought copper and brass, exported during the year 1799, was 1,222,187*l.*; and there is reason to believe, that the whole value of these manufactures at present is at least 3,500,000*l.*, and the number of persons employed 60,000.

The steel, plating, and hard-ware manufactures, including the toy-trade, have been of late much extended, and may probably amount in value to 4,000,000*l.*, and the persons employed to at least 70,000.

It is acknowledged, that many of these estimates must be essentially defective, from the want of public documents respecting many important branches of trade. However, they serve to shew, in a general view, the relative extent of our principal manufactures, as in the following summary:

	Annual Value.	Persons employed.
Woollen	£. 15,500,000	425,043
Leather	10,500,000	241,818
Cotton	9,500,000	322,140
Silk	2,700,000	60,000
Linen and flax	2,000,000	60,000
Hemp	1,500,000	35,000
Paper	900,000	30,000
Glass	1,500,000	36,000
Potteries	2,000,000	45,000
Iron, tin, and lead	10,000,000	200,000
Copper and brass	3,500,000	60,000
Steel, plating, &c.	4,000,000	70,000
	£. 63,600,000	1,585,000

To the above enumerated manufactures of greater importance, we might have added those of hats, horn, straw, &c. which taken together are of very considerable amount, and employ a great number of hands. There are also some, which, though not generally included among the manu-

factures, partake of the nature of these, and might, not improperly, be classed with them. To this head we might refer the elegant branch of exportation, or that of beautiful prints, for which this country is in an eminent degree indebted to the late alderman Boydell. Grellier, Month. Mag. Jan. 1801.

The commerce of Great Britain extends through the eastern and western hemispheres of the globe, by means of the capital and credit of the country, the skill and industry of its artizans and manufacturers, the number of its ships and the character of its seamen, and the enterprising spirit as

well as established reputation of its merchants. The number of registered vessels belonging to the British dominions, and employed in trade in 1802, was 20,568, their tonnage 2,128,055, and the number of seamen navigating the same, 154,530. In 1803, the number of vessels was 21,445; their tonnage 2,238,249; and the number of men 155,445; being an increase of 877 ships, of 110,194 tons, and of 915 men.

The following table will exhibit a complete view of British commerce solely from the port of London, for one year, ending Jan. 5, 1795, since which the commerce has increased.

Names of the Countries.	Value of Imports into London.			Value of Exports from the Port of London, to Foreign Parts.		
				British Manufactures.	Foreign Merchandize.	
	£.	s.	d.	£.	s.	d.
Ireland	2,209,501	3	4	168,687	18	3
British West Indies	6,072,117	5	0	2,249,043	13	11
Conquered Islands	1,226,064	13	8	260,976	0	11
British American Colonies	307,412	13	0	654,842	19	4
Guernsey and Jersey	91,936	1	2	12,001	13	10
Gibraltar	12,947	16	8	83,473	14	11
Honduras Bay	14,696	4	2	2,029	18	11
South Fishery	197,680	8	6	21	6	8
Asia, including East Indies	8,916,950	2	10	3,398,680	1	4
Africa	66,013	8	4	90,593	12	9
Turkey	641,860	19	2	32,065	12	0
Streights	8,399	14	0	—	—	—
Venice	82,107	16	0	6,203	17	11
Italy	1,215,012	15	0	80,980	18	9
Spain	1,070,697	18	0	205,096	4	4
Portugal	644,600	3	8	182,780	6	2
Madeira	7,479	16	8	27,998	6	10
Canaries	6,763	19	10	20,116	18	4
France	130	6	8	3,216	5	3
Austrian Flanders	137,249	5	0	129,413	9	7
Holland	1,203,515	3	6	114,458	3	7
Germany	1,089,307	19	4	1,044,634	18	0
Prussia	196,657	3	2	54,380	14	0
Poland	104,978	10	4	7,022	11	10
Sweden	262,727	3	4	33,845	5	6
Russia	1,269,688	9	6	95,519	8	8
Denmark and Norway	166,366	1	0	147,340	0	11
Greenland	26,753	11	2	—	—	—
United States of America	811,511	18	8	2,251,280	12	1
Florida	16,239	16	0	38,067	0	3
Foreign West Indies	56,240	2	0	1,767	13	10
Prize Goods	1,572,868	8	8	—	—	—
	29,706,476	17	4	11,396,539	13	8

Included in the account of each country.

RECAPITULATION.

The aggregate value of goods imported into London in one year	-	29,706,476	17	4
British manufactures exported	£. 11,396,539	13	8	
Foreign merchandize, do.	14,208,925	14	6	
Value of goods imported in upwards of 9000 coasting vessels, averaged at 500l. each.	4,500,000	0	0	
Value of goods exported coastways, in about 7000 vessels, at 1000l. each.	7,000,000	0	0	
	-	11,500,000	0	0
Total amount of property shipped and unshipped in the river Thames, in the course of a year, estimated at	-	66,811,942	5	6

If we add to this estimate, the accounts belonging to the other ports of Bristol, Liverpool, &c. the account must be enormous.

From the states of North America are chiefly imported tobacco, rice, indigo, timber, hemp, flax, iron, pitch, tar, and lumber; from the West Indies, sugar, rum, cotton, coffee, ginger, pepper, guaiacum, sarsaparilla, manchineal, mahogany, gums, &c.; from Africa, gold dust, ivory, gums, &c.; from the East Indies and China, tea, rice, spices,

drugs, colours, silk, cotton, saltpetre, shawls, and other products of the loom; from our remaining settlements in North America, furs, timber, pot-ash, iron; and from the various states of Europe, numerous articles of utility and of luxury. Pickerton's Geog. vol. i. p. 100.

For other particulars relating to Great Britain, see CONSTITUTION. DEBT, FUND, PARLIAMENT, REVENUE, &c. &c. See also ENGLAND, SCOTLAND, and WALES.

Buddle

BUDDLE, in *Mineralogy*, a name given by the English dressers of the ores of metals, to a sort of frame made to receive the ore after its first separation from its grossest foulness.

The ore is first beaten to powder in wooden troughs, through which there runs a continual stream of water, which carries away such of it as is fine enough to pass a grating, which is placed at one end of the trough; this falls into a long square receiver of wood, called the *launder*: the heaviest and purest of the ore falling at the head of the launder, is taken out separately, and requires little more care or trouble; but the other part, which spreads over the middle and lower end of the launder, is thrown into the buddle, which is a long square frame of boards, about four feet deep, six long, and three wide; in this there stands a man barefooted, with a trampling shovel in his hand, to cast up the ore about an inch thick, upon a square board placed before him as high as his middle; this is termed the *buddle-head*; and the man dexterously, with one edge of his shovel, cuts and divides it longwise, in respect of himself, about half an inch asunder, in these little cuts; the water coming gently

from the edge of an upper plain board, carries away the filth and lighter part of the prepared ore first, and then the metalline part immediately after, all falling down in the buddle, where, with his bare feet, he strokes it and smooths it, that the water and other heterogeneous matter may the sooner pass off from it.

When the buddle by this means becomes full, the ore is taken out; that at the head part, being the finest and purest, is taken out separate from the rest, as from the launder. The rest is again trampled in the same buddle; but the head, or, as it is called the forehead, of this buddle, and of the launder, are mixed together, and carried to another buddle, and trampled as at first. The foreheads of this last buddle, that is, that part of the ore which has fallen at the head, is carried to what they call a drawing buddle, whose difference from the rest is only this, that it has no tye, but only a plain sloping board, on which it is once more washed with the trampling shovel. Tin-ore, when it is taken from this, is called black tin, and this is found to be completely ready for the blowing-house. Phil. Trans. N^o 60. See *Dressing of ORE*.

Button

BUTTON, in its most ordinary acceptation, signifies a well known appendage to garments for conveniently fastening them together.

Trifling as this article may appear to some of our readers to be in itself, there is certainly no manufacture which includes such an infinite variety of operations as that of the button-maker. The number of substances of which they are made is almost inconceivable, and each requires a distinct

set of manipulations. Amongst them are gold, silver, plated copper, white-metal, pinchbeck, steel, japanned tin, glass, foil stones, mother of pearl, ivory, bone, horn, tortoise-shell, jet, cannel coal, paper, leather, and a thousand others; exclusive of those buttons which consist of a mould of wood or bone covered with silk or mohair, and the manufacture of which belongs to a different class of artisans. It would
very

very far exceed the limits of a work like the present if we were to enter into all the details of so multifarious a business as this: we shall therefore only trace a few outlines of the processes most ordinarily in use.

Of the manufacture of metal buttons. These are originally formed in two different ways; the blanks are either pierced out of a large sheet of metal with a punch driven by a fly-press, or cast in a pair of flasks of moderate size, containing 10 or 12 dozen each. In this latter case, the shanks are previously fixed in the sand, exactly in the centre of the impression formed by each pattern, so as to have their extremities immersed in the melted metal when poured into the flask, by which means they are consequently firmly fixed in the button when cooled. See **FOUNDRY**. The former process is generally used for yellow buttons, and the latter for those of white metal.

We shall first give an instance of the former mode of procedure as used in the manufacture of gilt buttons. The *gilding metal* is an alloy of copper and zinc, containing a smaller proportion of the latter than ordinary brass, and is made either by fusing together the copper and zinc, or by fusing brass with the requisite additional proportion of copper. This metal is first rolled into sheets of the intended thickness of the button, and the blanks are then pierced out as before mentioned. The blanks thus formed, are, when intended for plain buttons, usually planished by a single stroke of a plain die driven by the same engine, the fly-press: when for ornamented buttons, the figure is frequently also struck in like manner by an appropriate die, though there are others which are ornamented by hand. The shanks, which are made with wonderful facility and expedition by means of a very curious engine, are then temporarily attached to the bottom of each button by a wire clamp like a pair of sugar-tongs, and a small quantity of solder and resin applied to each. They are in this state exposed to heat on an iron plate containing about a gross, till the solder runs, and the shank becomes fixed to the button, after which, they are put singly in a lathe, and their edges turned off smoothly.

The surface of the metal, which has become in a small degree oxidated by the action of the heat in soldering, is next to be cleaned, which, in this, as in a great variety of other instances in the manufacture of metallic articles, is effected by the process of *stripping* or *pickling*; that is, some dozens of them are put into an earthen vessel pierced full of holes like a colander; the whole dipped into a vessel of diluted nitric acid; suffered to drain for a few seconds; again dipped successively into four or five other vessels of pure water, and then dried.

The next operation is the *rough burnishing*, which is performed by fixing the buttons in the lathe, and applying a burnisher of hard black stone from Derbyshire: the minute pores occasioned by the successive action of the heat and the acid are thus closed, and the subsequent process of gilding considerably improved, both with regard to economy and perfection.

The first step towards the gilding of all the alloys of copper consists in covering the surface uniformly with a thin stratum of mercury, by which means the amalgam, which is afterwards applied, attaches itself to it much more readily than it would otherwise do. This part of the process is called *quicking*, and is effected by stirring the buttons about with a brush in a vessel containing a quantity of nitric acid supersaturated with mercury; which latter is, of course, by the superior elective attraction of the copper for the acid, precipitated in its metallic state on the buttons, whose surfaces become uniformly and brilliantly covered with it. The mercury which hangs in loose drops on the buttons is then

shaken off by jerking the whole violently in a kind of earthen colander made for the purpose; and they are then ready for receiving the amalgam.

The amalgam is made by heating a quantity of grain gold with mercury in an iron ladle, by which means the former is soon dissolved, and the whole is then poured into a vessel of cold water. The superabundant mercury is strongly pressed out through a piece of chamois leather, and the remaining amalgam, which is of about the consistence of butter, is then fit for application.

This is performed by stirring the buttons, whose surfaces are already thinly covered, or wetted with mercury, in an earthen vessel with the requisite proportion of amalgam and a small quantity of diluted nitric acid, by which means the amalgam also attaches itself to their surfaces with a considerable degree of equality. The necessary quantity of gold is about five grains to a gross of buttons of an inch in diameter.

The next process is the volatilisation of the mercury by heat, which is usually called by the workmen *drying off*. This is performed by first heating the buttons in an iron pan, somewhat like a large frying pan till the amalgam with which they are covered becomes fluid, and seems disposed to run into drops, on which they are thrown into a large felt cap, called a *gilding cap*, made of coarse wool and goat's hair, and stirred about with a brush to equalize the covering of the surface by the gold. After this, they are again heated, again thrown into the gilding cap and stirred, and these operations successively repeated till the whole of the mercury is volatilised. This part of the process, as will readily be conceived, is extremely unwholesome, and has the most terrible effects on the constitution of the workmen, so that it would be no small desideratum, (and it does not seem to be difficult), conveniently to effect this agitation and friction of the heated buttons in a covered vessel; in which case also, though of inferior importance, the volatilised mercury might be saved. For preventing the waste and injury attending this process, an apparatus resembling that delineated in *Plate II. Miscellany, fig. 1.* has been partially and successfully adopted by Mr. Mark Sanders, an eminent button-maker of Birmingham.

"A hearth of the usual height is to be erected, in the middle of which a capacity for the fire is to be made; but instead of permitting the smoke to ascend into the top A, made of sheet or cast iron, through which the mercury is volatilised, a flue for that purpose should be conducted backwards to the chimney B. An iron plate, thick enough to contain heat sufficient to volatilise the mercury, is to cover the fire-place at the top of the hearth C. There must be an ash-hole, D, under the fire-place. The square space E, seen in the fire-place, is the flue, which serves to carry the smoke back under the hearth into the chimney B. The door of the fire-place and ash-pit may either be in front, as represented in the plate, or at the end of the hearth at F, which will perhaps less incommode the work-people. It would be of great advantage if the space between A and the iron plate C was covered up with a glass window coming down so low as only to leave sufficient room for moving the pan backwards and forwards with facility. If the sides were also glass instead of brick-work it would be still better, as the work-people would be able to have a full view of their work without being exposed to the fumes of the mercury, which, when volatilised by heat communicated to the pan by the heated iron plate over the fire-place, would ascend into the top A, appropriated for its reception, and descend into the tub G, covered at top and filled pretty high with water. By this means the hearth would, in fact, become a

distilling apparatus for condensing and recovering the volatilised mercury. In the tub G the principal part would be recovered; for, of what may still pass on, a part would be condensed in ascending the tube H, and fall back, while the remainder would be effectually caught in the tub or cask I, open at the top, and partly filled with water. The latter tub should be on the outside of the building, and the descending branch of the tube H should go down into it at least 18 inches, but not into the water. The chimney or the ash-pit should be furnished with a damper to regulate the heat of the fire.

The water may be occasionally drawn out of the tubs by a siphon, and the mercury clogged with heterogeneous matter may be triturated in a piece of flannel till it passes through, or placed in a pan of sheet iron, like a dripping pan, in a sufficient degree of heat, giving it a tolerable inclination, so that the mercury, as it gets warm, may run down and unite in the lower part of the pan. But the mercury will be most effectually recovered by exposing the residuum left in the flannel bag to distillation in a retort made of iron or of earthen ware.

When the mercury is volatilised from the buttons, or, as the workmen denominate it, when the buttons are dried off, they are finally burnished, and are then finished and fit for carding.

The reader unacquainted with this branch of manufacture will be surprised to learn how far a small quantity of gold, incorporated with mercury, will spread over a smooth surface of copper. Five grains, worth one shilling and threepence, on the top of a gross, that is, 144 buttons, each of one inch diameter, are sufficient to excuse the manufacturer from the penalty inflicted by an act of parliament; yet many, upon an assay are found to be deficient of this small quantity, and the maker fined and the buttons forfeited accordingly. Many hundred grosses have been tolerably gilt with half that quantity; so extremely far can gold be spread, when incorporated with mercury, over the surface of a smooth piece of copper". *Philosophical Magazine*, N° 33. p. 19, &c.

The white metal buttons which are composed of brass alloyed with different proportions of tin, after having been cast as before mentioned, are polished by turning them in a lathe, and applying successively pieces of buffalo skin glued on wood, (or *buffs* as the workmen call them) charged with powdered grindstone and oil, rotten stone and *crocus martis*. They are then *white-boiled*, that is, boiled with a quantity of grain tin in a solution of crude red tartar, or argol, and lastly, finished with a buff with finely prepared *crocus*.

Glass buttons. These articles are also frequently wholly composed of glass of various colours in imitation of the opal, lapis lazuli, and other stones. The glass is in this case kept in fusion, and the button nipped out of it whilst in its plastic state, by a pair of iron moulds, like those used for casting pistol shot, adapted to the intended form of the button: the workmen previously inserting the shank into the mould so that it may become imbedded in the glass when cold.

Mother of pearl buttons. This substance is also frequently used in the manufacture of buttons; in which case, the mode of fixing in the shank is somewhat ingenious. It is done by drilling a hole at the back which is under-cut, that is, larger at the bottom than the top, like a mortise, and the shank being driven in by a steady stroke, its extremity expands on striking against the bottom of the hole, and it becomes firmly rivetted into the button. To these, foil-stones are also frequently added, in which case, they are usually attached with isinglass-glue. Steel studs are also often ri-

vetted into buttons of this and various other kinds. See FOIL-STONES and STUDS.

Shell buttons. This name is given to those buttons which consist of a back which is generally of bone without any shank, but corded with catgut, and covered in front with a thin plate of metal struck with a die. They are now, however, much less in use than formerly. The backs are cut out with a brace whose bit is a circular saw, like that of a surgeon's trephine, and the four holes through which the catgut passes are drilled by four drills moving parallel to each other, and acting at once. They are then corded by children who tie the catgut on the inside; the cavity is filled with melted resin, and the metal shell applied warm. The button is then pressed between two centres in a lathe, which are forced together by a weight acting on a lever, (an ingenious application of this engine frequently made use of in this manufacture), and the edge of the shell turned down during its revolution with a small burnisher.

In the year 1790, a patent was granted to Mr. Henry Clay of Birmingham for a new method of manufacturing buttons of slate, or slit stone; and in 1800, Mr. Joseph Barnett of the same place obtained a patent for an improved mode of making buttons, by fixing two shanks, or other fastenings, on one button, one on each side, on the under surface, opposite to each other, instead of only one in the centre.

The practice of wearing buttons consisting merely of a mould covered with the same kind of cloth as the garment itself, being at present extremely general, it may perhaps be proper to remark, that this is prohibited on pain of pecuniary penalties, from 40s. to 5l. per dozen, by several statutes which have been made at different times for the promotion of this manufacture; and under which, several convictions have taken place within a few years. These are, 10 W. 3. c. 2. 8 Ann. c. 6. 4 Geo. c. 7. and 7 Geo. c. 17. The importation of buttons is prohibited on pain of forfeiture, and penalty of 100l. on the importer, and 50l. on the seller, by 13 & 14 C. II. c. 13. § 2. and 4 W. III. c. 10. § 2.

By 36 Geo. III. c. 60. any person putting false marks on gilt buttons, erasing any marks except such as express the real quality, or any other words, except *gilt* or *plated*, incurs the penalty of forfeiting such buttons, and also 5l. for any quantity not exceeding 12 dozen; and if above, after the rate of 1l. for every 12 dozen. The penalty, however, does not extend to those who mark the words *double* and *treble gilt*, provided, in the case of double gilt buttons, gold shall be equally spread upon their upper surface, exclusively of the edges, in the proportion of 10 grains to the surface of a circle 12 inches in diameter; and in that of treble gilt, the gold shall amount to 15 grains in the same proportion. The penalty on making false bills of parcels, expressing any other than the real quality of such buttons, is 20l.; and that on mixing buttons of different qualities, forfeiture of the same, and 5l. for any number between one and 12 dozen, and above this number, 1l. for every 12 dozen. In order to ascertain what shall be deemed gilt or plated buttons, gilt buttons shall have gold equally spread upon the upper surface in the proportion of five grains to the surface of a circle 12 inches in diameter; and plated buttons shall have the superficies of the upper surface made of a plate of silver fixed upon copper, or a mixture of it with other metals, previously to its being rolled into sheets or fillets. All pecuniary penalties may be recovered by action or suit within three calendar months, in the courts of Westminster, and one justice may, by warrant, cause metal buttons liable to

forfeiture, to be seized and kept in safe custody, to be produced as evidence upon any action, or cause them to be destroyed. Pecuniary penalties may also be adjudged by two justices in the place where the offender resides, or the offence is committed. This act, however, does not extend

to buttons made of gold, silver, tin, pewter, lead, or mixture of tin and lead, or iron tinned, or of Bath or white metal, or any of these metals inlaid with steel, or buttons plated upon shells.

Calendar

CALENDER, a machine used, in the manufactories, for pressing certain stuffs, silks, callicoes, and even linens; to make them smooth, even and glossy. It is also used for watering, or giving the waves to tabbies and mohairs.

The word is formed from the French *calandre*, or Spanish *calandra*, which signify the same; and which some derive further from the Latin *cylindrus*; because the whole effect of the machine depends upon a cylinder. Borel derives the name from that of a little bird, of the swallow kind; on account of the agreement between the feathers of the bird, and the impression of the machine.

The calender consists of two large wooden rollers, round which the pieces of stuff are wound: these are put between two large, close, polished planks of wood, or plates of iron, the lower serving as a fixed base, and the upper moveable, by means of a wheel like that of a crane; with a rope, fastened to a spindle, which makes its axis: this upper part is of a prodigious weight, sometimes twenty or thirty thousand pounds. It is the weight of this part, together with its alternate motion, that gives the polish, and makes the waves on the stuffs, by causing the cylinders on which they are put to roll with great force over the lowest board. The rollers are taken off, and put on again by inclining the

machine.

At Paris they have an extraordinary machine of this kind, called the *royal calender*, made by order of M. Colbert; the lower table or plank of which is made of a block of smooth marble, and the upper lined at bottom with a plate of polished copper.

This is called the great calender; they have also a small one with two tables of polished iron or steel.

There are also calenders without wheels, which are wrought by a horse harnessed to a wooden bar, which turns a large arbor placed upright; at the top of which, on a kind of drum, is wound a rope, the two ends of which being fastened to the two extremities of the upper plank of the engine, give it motion. But the horse calendar is in less esteem than the wheel kind, as the motion of this latter is more equable and certain.

We read of calendering workeds. To improve linen farther, the drapers get several sorts of their cloths calendered: whereby their threads are made to lie flatter and smoother.

CALENDER also denotes the workman who manages the machine above described; applying the cloth or stuff underneath, after having first wound it on the rollers.

Camera

CAMERA *Æolia*, a contrivance for blowing the fire, for the fusion of ores, without bellows; by means of water falling through a funnel into a close vessel, which sends from it so much air or vapour as continually blows the fire: if there be the space of another vessel for it to expatiate in by the way, it there lets fall its humidity, which otherwise might hinder the work. The contrivance was named *camera Æolia* by Kircher. Hook, Phil. Coll. N^o 3. p. 80. See **BELLOWS**,

CAMERA *lucida*, a contrivance of Dr. Hook for making the image of any thing appear on a wall in a light room, either by day or night. Opposite to the place or wall where the appearance is to be, make a hole of at least a foot in diameter, or if there be a high window with a casement of this dimension in it, this will do much better without such hole, or casement opened. At a convenient distance, to prevent its being perceived by the company in the room, place the object or picture intended to be represented, but in an inverted situation. If the picture be transparent, reflect the sun's rays by means of a looking glass, so as that they may pass through it towards the place of representation; and to prevent any rays from passing aside it, let the picture be encompassed with some board or cloth. If the object be a statue, or a living creature, it must be much enlightened by calling the sun's rays on it, either by reflection, refraction, or both. Between this object and the place of representation put a broad convex glass, ground to such a convexity, as that it may represent the object distinctly in such place. The nearer this is situate to the object, the more will the image be magnified on the wall, and the further the lens; such diversity depending on the difference of the spheres of the glasses. If the object cannot be conveniently inverted,

there must be two large glasses of proper spheres, situate at suitable distances, easily found by trial, to make the representations erect. This whole apparatus of object, glasses, &c. with the persons employed in the management of them, are to be placed without the window or hole, so that they may not be perceived by the spectators in the room, and the operation itself will be easily performed. Phil. Trans. N^o 38, p. 741, seq.

CAMERA *Obscura*, or **DARK CHAMBER**, in *Optics*, a machine or apparatus so constructed, that principally by means of a convex glass, or a convex glass and plane mirror, the images of external objects are represented on a rough ground plane glass, white paper, white wall, or other surface, in the most vivid and distinct manner, with all their natural motions, colours, shades, &c. The first invention of the camera obscura has been ascribed to Baptista Porta.—See his *Magia Naturalis*, lib. xvii. cap. 6. first published at Frankfort about the year 1589 or 1591. The first four books of this work were published at Antwerp in 1560. But Dr. Freind, in his "History of Physic," (vol. ii. p. 236) observes, that friar Bacon, who flourished in the beginning of the 13th century, describes the camera obscura, and all sorts of glasses, which magnify or diminish any object, bring it nearer to the eye, or remove it farther off. See also Bacon's "Opus Majus" by Dr. Jebb, p. 236; and his Epistle "ad Parisienses," and his "Perspective" cited by Dr. Plott in his "History of Oxfordshire," p. 21; from which we may conclude, that he had a very accurate and extensive acquaintance with the properties of various kinds of glasses.

CAMERA *Obscura*, the use of the, is manifold: it assists very much in explaining the nature and rationale of vision, and hence

hence by some it has been compared to the artificial eye. It exhibits the most striking and entertaining representations of objects of all descriptions, whether near or distant, in their true perspective, the colouring just and natural, their light and shadows correct, and all their motions and relative positions according to the original. By means of this instrument, a person however unacquainted with drawing, may delineate objects with great facility and correctness; and to the skilful artist it will be found indispensably useful in comparing his sketches with the perfect representations given in the camera, and by observing his defective imitations, he may correct, as much as possible, his designs. To the delineations of that beautiful representation called the *Panorama*, this instrument has proved of essential use.

CAMERA Obscura, the theory of the, is contained in the following proposition.

If an external object, as *A*, *Plate III. Optics, fig. 1*, radiates its light through a small aperture *C*, in a shutter of a perfectly darkened room upon a white paper or painted screen opposite to it, an image of the object will be depicted on the screen in an inverted position. For the aperture *C* being supposed very small, the rays issuing from the point *B* will fall on *b*: those from the points *A* and *D* will fall on *a* and *d*; wherefore, since the rays issuing from the several points are not blended, they will, by reflection, exhibit its appearance on the screen. But since these rays, *AC* and *BC*, intersect each other in the aperture, and the rays from the lowest points fall on the highest, the situation of the object will necessarily be inverted. Hence, since the angles at *D* and *d*, and the vertical ones are equal at *C*, *B* and *b*, and *A* and *a*, will be also equal; consequently, if the screen where the object is delineated be parallel to it, $ab : AB :: dC : DC$.

That is, the height of the image will be to the height of the object, as the distance of the image from the aperture is to the distance of the object from the same. This proves, therefore, that the inversion of the object is not owing to any lens that may be used in a camera obscura. In this manner, the figures of the image are very faint and confused, for want of a due degree of light, and its proper refractions.

CAMERA Obscura, construction of a, whereon the images of external objects are distinctly represented in their genuine colours, light and shade, &c. and either in an erect or inverted position.

1. Darken, in the most perfect manner possible, a room or chamber; in the shutter of one of the windows that faces the object to be represented, cut a small circular aperture, see *fig. 1. C*.

2. In this aperture fix either a double or plain convex lens; if the latter, with the convex side next the object. Its focus may be of any length between 3 and 6 feet.

3. At a proper distance, to be determined by experiment, or about the focal distance of the lens, place perpendicularly a large surface of white paper or cloth, and on this the images of the external objects directly before the lens will be beautifully delineated, but in an inverted position. The paper or cloth should be moveable, so that the exact distance of the focus of the lens may be obtained, or the images will not be shewn with their utmost distinctness. Those objects also should be selected that are in the strongest light, or illuminated by the sun's rays. In northern latitudes at noon-day, a window opposite the north is best; in the morning, facing the west, and in the evening facing the east. In southern latitudes a window facing the south is best at noon. The shorter the focus the smaller and brighter the images will appear; and the longer, the larger the objects; but if

the focus be very long, from 20 to 30 feet, the same light being more dilated or spread over a large surface, the images will appear somewhat obscure, and the colouring fainter. The images will be still brighter if the spectator first stay a quarter of an hour in the dark.

This is the most perfect method of obtaining a representation of objects, from having but one refracting medium, but in some cases the inverted position of the images may be some objection; to obviate which, the following methods may be used to make the picture erect. Hold a true ground plain mirror slantwise against your breast, under an acute angle, and looking therein, you will see all the images restored to their natural and erect position, and with an addition of lustre that they will receive from the reflection of the mirror. Or, which is a better way, and does not require a mirror near so large, place a mirror above and rather near the lens, so as to reflect the rays down upon a white surface, a screen directly under, or parallel to the mirror. Or, a large concave mirror may be placed before the picture, at such a distance that the image of the picture may appear before the mirror, which will then be erect, and appear pendant in the air. Another method, which is more direct, is by placing another convex lens in a partition behind the paper or screen, with the image at twice the focal distance of the said lens, the axes of the two lenses coinciding, in which case another picture of the images will be formed but erect, as large as the first, but not so bright, and with a contracted field or extent of the picture. Or, two lenses of short foci in draw-out tubes, may be applied to the hole in the shutter instead of one, which will also produce an erect position of the images, but the light will be less, the extent very limited, and serve only for the representation of busts, small figures, &c. as hereafter to be described. This method is but of little use and seldom practised.

The following description of cameras obscuras has been communicated to us by Mr. William Jones, optician, Holborn, as being the most commodious and perfect, and what have been preferred, and are in general use, by the most skilful artists:—

Fig. 2. represents the sciopic ball, which is made of mahogany, and consists of three parts, a frame, a ball, and a lens. The frame consists of two pieces in a circular screw rim, fitted one to the other, and both so excavated as to admit, and keep steady a spherical ball perforated, which is voluble in its frame more or less easily, as the parts of the frame are less or more screwed together. At each end the hole in this ball is a screw cell for containing a lens; these lenses are of different focal lengths, and only one is to be used at a time, when the images are to be formed. The frame of this sciopic ball is to be screwed fast to the window shutter or window board of a well-darkened room, before a hole previously made therein. There are two brass nuts and screws, *a, b*, fitted to the frame for that purpose; the nuts are screwed to the shutter or board, so that by means of the screws the sciopic ball may be the more readily attached to, or detached from, the shutter. This apparatus is very convenient, when experiments by a variety of lenses may be desired. *A, fig. 2*, represents the position of a mirror when applied for reflecting downwards the images in order to obtain the erect positions; if the frame be made to turn on an hinge, it will be the more useful to direct the image to an oblique screen, or table, as may be required. *Fig. 1.* represents a darkened room with a lens attached to the side or shutter, or where the sciopic ball is to be placed. *E* represents the moveable white paper screen that receives the images of the objects formed by the lenses, and is moveable to the distance of the focal length of the glass. *AB* shews the manner in which the bust, &c.

ture, or picture, may be fixed on a support on the outside of the window, so that an image may be formed upon the paper within, from which the artist is to copy or delineate. For such proximate objects the focus of the lens must be short, from 9 to 12 inches, or the screen will be required to be at too remote a distance from the lens. When the distance of the object and the image are the same from the lens, the image will be of the same size as the object. When the object approaches nearer, the image will recede and enlarge, and *vice versa*.

To exhibit Solar Phenomena by means of the Scioptic Ball and Socket.

The scioptic ball affords a very convenient method of forming an image of the sun in the darkened room. If a lens 10 or 12 feet focus be placed on it, and a white paper screen placed at its focus, in a perpendicular position to the rays, a distinct image of the sun will be formed, about one inch diameter, on which will be conspicuously exhibited all the spots or solar maculæ. At the time of a solar eclipse, the whole progress of the moon, from the time of the first contact of the limbs to the last, may, in this way, be observed very distinctly. But the best method is by connecting a draw-out telescope, with the ball of the socket, *fig. 2.* by screwing the end with the object glass to it, and taking out all the eye glasses at the other end, except the one next to the eye, then moving inwards the first tube till the image of the sun appear distinct; and you will have a bright image from 12 to 20 inches diameter, according to the distance of the screen, which will, to any number of spectators, exhibit the solar phenomena intended to be viewed.

Construction of a Chamber Camera Obscura.

The foregoing is the readiest and most simple method of converting a room into a camera obscura, but it is attended with these objections, that it only serves for objects directly facing the lens, and occasions always the trouble of darkening the room, fixing and adjusting the apparatus, &c. *Fig. 3.* represents a roof shaded like a dome or cupola, placed over a building, prospect-room, or temporary room erected for the purpose of a camera obscura, and in this way affords the most ready and advantageous plan for all surrounding objects. The whole dome A B may be made to turn round on friction wheels, in a groove made in the roof for that purpose, and to carry round with it the glasses in the box C above, or which, in some cases, is a more manageable way, the box with the glasses is made moveable in a groove round upon the dome, and is turned by means of a long rod by a person within. The manner of fabricating such a dome and box will be evident to any good joiner by a mere inspection of the figure. The mahogany box C is of a cubical form about 6 or 7 inches in the length of a side; a true ground mirror in a frame is placed diagonally in the box, and is moveable somewhat on an axis at its lower edge upwards and downwards, to reflect the rays from objects at various distances; underneath this mirror, in a round cell, at the bottom of the box, is fixed a double convex lens, about 6 or 8 feet focus, and 4 or 4½ inches in diameter: this lens will form upon a white table D, placed on the floor below, the images of the objects reflected by the mirror above, at the focal distance of the lens. The diameter of this table should be 2½ or 3 feet, excavated on its surface to a small degree of concavity, or from a radius about the focus of the lens, in order, that the inequality of the distance of its surface from the centre of the lens, presenting the images indistinct at the circumference, when they are clear in the middle, may be obviated. The surface must be painted perfectly white, or, which is better, covered with a thin coating of plaster or stucco. The pillar of the table should be made with a screw working in a female one out

in the pedestal, so that by turning round the table and screw its surface may either be elevated or depressed, as may be necessary, to admit of the clearest and best defined picture of the images possible. To persons having dwellings upon elevated situations commanding extensive prospects over countries, rivers, the sea, &c. a machine of this kind constructed over it will afford more delight and entertainment, as well as use to an artist, than any person would imagine, who had not previously been a witness to such an effect. To those who may not wish to be at the expence of a dome, Mr. Jones recommends the box fitted to a wooden pyramidal trunk, (see *fig. 4.*) which trunk can be fixed on the ridge of the roof of a house or chamber, by a common carpenter, and a flat sliding cover to slide on at A, to cover the trunk when the box of glasses B is taken away after use. The camera boxes, with the glasses complete, and ready for fixing, are made by Messrs. Jones, of H. Horn, and other Opticians. Metallic mirrors have been used instead of glass ones for cameras; they reflect more light, and consequently shew the images brighter, but their liability to tarnish and corrode is an insurmountable objection to their general use.

CAMERAS Obscuræ, construction of portable. The glasses of a camera obscura are frequently fitted to a portable machine shutting up in the form of a chest, or book, to as to be portable, and easily transported from place to place, and carried about by the artist. The apparatus within is contrived to fold outwards, and form a machine as represented at *fig. 5.* and it is contrived upon the most convenient plan of any hitherto constructed. It is represented as placed together for use. The lid front A, and the slides, one shewn at B, by means of hinges turn up to the height of about two feet from the case C D E, and are fastened together by small brass hooks. The head and sliding box, with glasses F, also fasten on by hooks within. The lens of about 25 inches focus is placed under the true parallel glass mirror, and forms the images on a white sheet of paper, placed in the bottom of the chest. To view the images the face is applied close to a piece under A for that purpose, and to trace the outline, or copy them, the arm at the same time is applied in the cloth sleeve under H. The box F slides on a square tube, and by means of a brass rack and pinion G the lens is adjusted, while the images are viewing, to its proper focal distance from the white paper below. The images formed on the paper have a correct and natural resemblance to the original objects; no inversion takes place, and even names and letters on objects are in their direct order. This camera is converted into an instrument for magnifying perspective prints and drawings, and forms the best possible apparatus for that purpose. The head F G and tube are to be entirely removed, as well as the front A, and cloth C D, and another head with a diagonally-placed mirror and large convex lens, *fig. 6.* substituted, and also hooked on. The prints are to be placed at the bottom of the chest, and as the camera case is open, the print will be illumined either by day light or candle light, as required. The print is viewed by reflection in an horizontal direction, by the eyes being placed before the large convex lens. When the sides and front are unhooked and folded down into the chest, they all lie close, and admit the head to lie under them; and the dimensions of the chest, when thus shut up, do not exceed 2 feet in length, 20 inches in breadth, and 5 inches in depth.

The most portable kind of Camera obscura is that represented at *fig. 7.* and is that most frequently used among artists, on account of its convenient dimensions. The images are reflected on a rough ground plane glass, and are more vivid than those formed on paper, by the Camera above described. It is made of mahogany, and of various dimensions,

some so small as to be carried in the pocket. The lens at the front *A* is fixed in the cell, in the front of a square draw-out tube, and is of a focus equal to the length of the box when the drawer is half drawn out; and a plain mirror is placed diagonally at the angle of 45° , at the end of the box, as shewn by the dotted line *ab*, which reflects the rays transmitted by the lens up to the upper side of the plane rough-ground glass, the rough side placed above, under the folding darkening cover, and there forming the images of the objects before the lens at *A*: the use of the draw is to adjust the proper distance of the lens from the mirror, according to the variable distances of proximate objects. The images on the rough glass exhibit a beautiful perspective picture, also the profile of a person seated in a room in a strong light before the camera, and more particularly if the sun illumine the object; and may be readily traced on the rough surface of the glass by a black lead pencil, or by what is preferable, red French chalk, and then white paper being gently placed on the glass, the lines will be taken correctly off. If very thin white paper is merely placed upon the glass, the images may be discerned, though faintly, sufficient to afford the means of tracing correctly. The nearer the object or features are to the camera the larger will be the image, and an additional lens of a shorter focus is sometimes fitted to be substituted for the other, when the images of very near objects are wanted. Some artists who take profiles take out the rough glass from its cell, invert the camera, and by a stand sup-

port it about 10 or 12 inches above the white paper on the table. The image will then invertedly be formed on the paper, and they trace it with a pencil in a correct manner, and with less trouble than by the other method. Messrs. Jones, of Holborn, make an improved camera of this kind, by joining the side of the camera and drawer in the middle with canvas cloth, as shewn at the lines *B C*: the back *C* turns inward with the mirror, close up to the rough glass, and the front *E F* above, over the top, so that the whole camera may fold down into a flat form, and go into a very portable flat leather strap case, making it the most portable possible for persons travelling. Inclusive of the rough glass has sometimes been placed a double convex lens to relieve the images, and from more light being thus refracted, the images are shewn with great beauty and extraordinary brightness, even surpassing the original. They are also more vivid when the rough glass is placed over this lens, though the contours, or outlines, are not so sharp or distinct as when the rough glass is used only by itself. This improvement was assumed some years ago, by a person of the name of Stoicer, as a discovery, and called a *delinicator*, but without the least pretensions, it being previously well known by the most eminent opticians, and it was, in the year 1758, noticed by Mr. Hooper, in his *Rational Recreations*, vol. ii. p. 20. Guyot's *Recreations Physiques*, tom. ii. recr. 35. art. 2. Mr. Harris, in his "Optics," b. ii. § 4. has described a variety of contrivances for converting the portable camera into a shew box for viewing prints.

Canal

CANAL, *Canalis*, in general, denotes a long, round, hollow instrument, through which a fluid matter may be conveyed.

In which sense, it amounts to the same with what we otherwise call a pipe, tube, channel, &c. Thus the *canal* of an aqueduct, is the part through which the water passes; which, in the ancient edifices of this kind, is lined with a coat of mastic of a peculiar composition.

CANAL, a duct or pipe (as its derivation from the Latin *Cana*, a cane, or reed, seems to imply), in which sense it is used by anatomists in describing the passage through which some of the animal fluids pass: the term Canal has also been applied to denote any piece of water, especially if of a considerable length in proportion to its width, and especially such as are stagnant, or have not the fall and natural motion which rivers have. Canals may be either for pleasure or ornament, such as are common in the vicinity of palaces and great houses; or applied to the purposes of inland navigation. The artificial carriages for conveying streams of water for the supply of cities or other purposes, as was done by the famous aqueducts of antiquity, and in modern times by the new rivers near London, and others, have sometimes also been called Canals.

The importance and utility of canals have been so long and so generally acknowledged, that it is hardly necessary to introduce the subject with any observations to this purpose. Few persons have more attentively considered or better understood the political and commercial interests of nations than the late Dr. Smith; and no one could be a more zealous advocate for the extension of inland navigation, as an effectual means of improving the country, in which it is encouraged. To this purpose he observes, in his "*Wealth of Nations*" (vol. i. p. 229.), that good roads, canals, and navigable rivers, by diminishing the expence of carriage, put the remote parts of the country more nearly upon a level with those in the neighbourhood of large towns; and on that account they are the greatest of all improvements. They encourage the cultivation of the remote parts, which must always be the most extensive circle of the country. They are advantageous to towns, by breaking down the monopoly of the country in its neighbourhood; and they are advantageous to all parts of the country; for though they introduce some rival commodities into the old markets, they open many new markets to its produce. "It is not more than 50 years ago," says he in 1776, when the first edition of his work was printed, "that some,

of the countries in the neighbourhood of London, petitioned the parliament against the extension of the turnpike roads into the remoter counties. Those remoter counties, they pretended, from the cheapness of labour, would be able to sell their grass and corn cheaper in the London market than themselves, and would thereby reduce their rents, and ruin their cultivation. Their rents, however, have risen, and their cultivation has been improved since that time." "All canals," says an intelligent writer on this subject (See Phillips's General History of Inland Navigation, Introd.), "may be considered as so many roads of a certain kind, on which one horse will draw as much as 30 horses on ordinary turnpike roads, or on which one man alone will transport as many goods as three men; and 18 horses usually do on common roads. The public would be great gainers were they to lay out upon the making of every mile of a canal twenty times as much as they expend upon a mile of turnpike road; but a mile of canal is often made at a less expence than the mile of turnpike: consequently there is a great inducement to multiply the number of canals."

The advantages resulting from canals, as they open an easy and cheap communication between distant parts of a country, will be ultimately experienced by persons of various descriptions: and more especially by the manufacturer, the occupier or owner of land, and the merchant. The manufacturer will thus be enabled to collect his materials, his fuel, and the means of subsistence, from remote districts, with less labour and expence; and to convey his goods to a profitable market. As canals multiply, old manufactures revive and flourish, new ones are established, and the adjoining country is rendered populous and productive. To the occupier of land, canals are useful in a variety of ways. In some cases, they serve the purposes of draining and of irrigation; in others, they furnish manure at a cheap rate; and they facilitate the conveyance of the produce to places where it may be disposed of to the greatest advantage. The landowner must of course be benefited, by the increasing value and advanced rent of his estate, in consequence of the improvement it receives from the industry of the occupier, excited and encouraged by an immediate recompence. The wholesale trader and merchant are likewise enabled to extend their commerce by means of canals; as they can thus export greater quantities and varieties of goods from places remote from the sea, and easily supply a wider extent of inland coun-

country with the commodities that are imported from foreign nations. Nor are they merely the means of extending and increasing foreign commerce, but they serve also to create and augment an internal trade, which, with all the advantages attendant on foreign commerce, may probably far exceed it in extent, value, and importance. We might add, that an inland communication between parts of a country, at a great distance from one another, contribute to the security, as well as to the extension of commerce, in the boisterous months of winter, and in times of war, when the navigation of the seas would be attended with danger. "Were we to make the supposition of two states," says Mr. Phillips (*ubi supra*), "the one having all its cities, towns, and villages upon navigable rivers and canals that have an easy communication with each other; the other possessing the common conveyance of land-carriage; and supposing, at the same time, both states to be equal as to soil, climate, and industry; commodities and manufactures, in the former state, might be exported 30 *per cent.* cheaper than in the latter; or, in other words, the first state would be a third richer and more affluent than the second." Should it be objected, that navigable canals waste or occupy too great a portion of land in the countries through which they pass, the objection may be obviated by the consideration, that one mile of a canal, 14 yards wide, takes up little more than five acres of land.

If we advert to fact, and consult the records of history with regard to the state of different nations, we shall find, that civilization and commerce have very much depended on the facility with which the inhabitants of remote districts have maintained intercourse with one another, as well as with distant countries. As the ocean serves to connect distant countries, navigable rivers and canals unite the different provinces and districts of the same country; and as navigation, by means of the ocean, produces an intercourse and mutual exchange of productions between different kingdoms, inland navigation, in like manner, facilitates a communication between different parts of the same kingdom, and consequently promotes trade and industry. In North America, the plantations have constantly followed either the sea-coast or the banks of the navigable rivers, and have scarcely any where extended themselves to any considerable distance from the one or the other. The nations that appear to have been first civilized, were those that dwelt round the coast of the Mediterranean sea, which, from a variety of circumstances, was extremely favourable to the early navigation of the world. Of all the countries on the coast of the Mediterranean, Egypt seems to have been the first, in which either agriculture or manufactures were cultivated and improved to any considerable degree. Upper Egypt extends itself nowhere above a few miles from the Nile, and in Lower Egypt that great river breaks itself into many different canals, which, aided by a small degree of art, seem to have afforded a communication by water-carriage, not only between all the large towns, but between all the considerable villages, and even to many farm-houses in the country; nearly in the same manner as the Rhine and the Maese do in Holland at present. The extent or facility of this inland navigation was probably one of the principal causes of the early improvement of Egypt. The improvement in agriculture and manufactures seems likewise to have been of very great antiquity in the provinces of Bengal in the East Indies, and in some of the eastern provinces of China. In Bengal, the Ganges and several other large rivers form a great number of navigable canals, in the same manner as the Nile does in Egypt. The case is the same in the eastern provinces

of China, where several large rivers form, by their different branches, a multitude of canals, and by communicating with one another afford an inland navigation much more extensive than that either of the Nile or the Ganges, or perhaps of both of them united. It is remarkable, however, that neither the ancient Egyptians, nor the Indians, nor the Chinese, encouraged foreign commerce; but they all seem to have derived their extraordinary opulence from this inland navigation. On the other hand, those nations that have been destitute of the means of inland navigation, either by rivers or canals, have remained from one age to the other in the same barbarous and uncivilized state. This observation is exemplified in the state of all the inland parts of Africa, and of that part of Asia which lies at any considerable distance north of the Euxine and Caspian sea, the ancient Scythia, and the modern Tartary and Siberia. The commerce that may be carried on by means of a river, which does not break itself into any great number of branches or canals, and which runs into another territory before it reaches the sea, can never be very considerable; because it is always in the power of the nation who possesses that other territory to obstruct the communication between the upper country and the sea. Thus the navigation of the Danube is of very little use to the different states of Bavaria, Austria, and Hungary, in comparison of what it would be if any of them possessed the whole of its course till it falls into the Black Sea. To these general observations, we shall subjoin a brief account of the principal canals that have been formed among the nations of antiquity, and among foreign nations in later times; reserving the principal part of this article for an enumeration of the canals of our own country, and for an illustration of the principles on which they are constructed, the regulations to which they are subject, and the various uses to which they are applied.

In the history of ancient nations we discover various traces of canals, formed for military, agricultural, commercial, or other purposes. The "*fossumes Philistinæ*" of Pliny (l. iii. c. 16.), which were large canals at the mouth of the Eridanus in Liguria, are ascribed by Mr. Bryant to the Canaanites, and particularly to the Caphtorim, who at a remote period migrated from Philistia; and hence these outlets of the river were named "*Philistinæ*." We learn from Herodotus (l. i. c. 174.) that the Cnidians, a people of Caria in Asia Minor, formed a design of digging a channel through the isthmus which joined their territory to the continent; but they relinquished the undertaking, because they were interdicted by an oracle. Strabo informs us (l. ix. p. 406, &c.) that canals and pits were dug in Bœotia, at a very remote period of antiquity, for drawing off the water of the lake Copais, which would otherwise have overflowed the whole country. This lake near the sea terminates in three bays, which advance to the foot of mount Ptoos, situate between the sea and the lake. From the bottom of each of these bays numerous canals were made to diverge and traverse the mountain through its whole breadth, some of which were more than a league in length, and others of a much greater extent. For the purpose of excavating or of cleansing them, very deep wells had been sunk at stated distances on the mountain. The labour of forming and the expence of maintaining these canals must have been immense. They have since been almost wholly neglected, so that most of them are choked up, and the lake seems to be gaining on the plain. The inhabitants of Babylonia or Chaldaea guarded against the detrimental inundations of the Tigris and Euphrates by a great number of artificial rivers and canals, which served to distribute waters, to benefit the country

in general, and to effect an easy communication and intercourse between the occupiers of different parts of the country. The Euphrates, according to Ptolemy (l. v. c. 17.), above Babylon, near a town in Mesopotamia, called Sippbara, divides itself into two branches, one running to Babylon, and the other to Seleucia, where it falls into the Tigris. The latter, says Pliny (l. vi. c. 26.), was partly artificial; and he places Seleucia at the confluence of the Tigris and Euphrates, adding that the Euphrates was conveyed to it by a canal. Prideaux, (Conn. b. ii. part i. p. 103.) on his authority, supposes that branch to have been artificial, and ascribes it to Nebuchadnezzar. Between these two branches an artificial canal was cut from the Euphrates, above Babylon, to the Tigris at Apamea, 60 miles below Seleucia. This canal, which was large and navigable, was called *Naarmalcha*, which see. From the Naarmalcha the emperors Trajan and Severus, in their wars with the Parthians, dug a new canal to the Tigris, near Coche on the west, and Ctesiphon on the east side of that river. At the distance of 800 furlongs from Babylon, to the south was another canal, called by Arrian (Exped. Alex. l. vii.) Pallacopas, and by Appian (Bell. Civil. l. ii.) Pallacotta, derived from the branch of the Euphrates that passed through Babylon and conveyed water to certain lakes or marshes in Chaldaea. On this canal, or river, as Arrian calls it, Alexander failed from the Euphrates to these lakes. Strabo (l. xvi.) describes the course of this canal, without naming it. But it is impossible to trace out, with accuracy, these and the other numerous branches and canals which watered the ancient country of *Babylon*, which see. Many of those that were formerly considerable are now lost; and others have been formed since, that did not exist in ancient times; for a country so much watered, so low in situation, and so subject to the violence of extraordinary inundations from the two large rivers, the Tigris and Euphrates, and so neglected as it has been for several ages, must have often and very considerably changed its face since the time of Ptolemy; and it is almost impossible to describe it such as it was while it continued to be the seat of empire, when the inhabitants were rich enough to take care of its numerous banks, and to keep them in repair. See *BABYLONIA*.

Both the Greeks and Romans proposed to make a canal across the isthmus of Corinth, which joins the Morea and Achaia, and thus to make a navigable passage by the Ionian sea into the Archipelago. Demetrius Poliorcetes, Julius Cæsar, Nero, and Caligula renewed the attempt, but without success. Plin. l. iv. c. 4. After the death of Alexander the Great, Seleucus Nicanor attempted to make a canal between the Euxine and Caspian seas, but his undertaking proved abortive. Travellers, however, assert that traces of very deep vallies are to be seen, through which the canal is said to have passed. Selim II. and Peter the Great, renewed the attempt, but they were prevented from succeeding, not so much by the impracticability of the scheme as by other collateral circumstances. The Romans, more intent on conquests than on commerce and the arts, afford us few instances of canals for internal navigation. We find, however, that Drusus, under the emperor Augustus, having conceived the design of marching into Germany without harassing his troops by a long and difficult march, facilitated the execution of it by making a canal that communicates from the Rhine with the Issel, extending from the village of Iseleort to Doelbourg. This canal received a great part of the waters of the right branch of the Rhine, which became by that means much less considerable. At the same time he opened a third mouth from that river into the sea, mentioned by Pliny under the name of "*Flevum Ostium*." But the face of the country has been much altered from that time. Lu-

cius Verus who commanded the Roman army in Gaul under Nero, attempted to make a canal between the Moselle and the Rhine. Corbulo under Claudius employed his soldiers in digging a canal between the Rhine and the Maese, though an interval of about 23 miles, in order to preserve the country from inundations, and to serve as a drain, in case of any extraordinary overflowings of the sea. Cluverius and Cellarius suppose this to be the canal that begins at Leyden, passes by Delft, continues on to Macfland, and joins the Maese at the village of Sluys. Claudius also employed 30,000 men for about 12 years in digging a canal through a mountain for draining the lake Fucinus (now Celano) into the river Liris; and in 1789 this canal was begun to be cleaned to the great relief of the neighbouring country, which was inundated by its obstruction. The Romans, during their residence in this country, made a canal between the Nyne, a little below Peterborough, and the Witham, 3 miles below Lincoln, called by the modern inhabitants "*Caerdike*," which is now almost wholly filled up. It was almost 40 miles long, and, as far as we may judge from the ruins, very broad and deep. Some have supposed it to be a Danish work. J. Morton supposes it to have been made under the emperor Domitian. Urns and medals have been discovered on the banks of this canal, which seem to confirm that opinion. Moiton's Hist. Northamptonshire, ch. 10. Charlemagne, at a later period, formed a design of joining the Rhine and the Danube, and of thus making a communication between the ocean and the Black sea, by a canal extending from the river Almutz, which discharges itself into the Danube, to the Reditz, which falls into the Maine; and the Maine joins the Rhine near Mayence. In the execution of this design he employed a great number of workmen, but he was prevented from completing it by a variety of obstructions which occurred. Of all the countries to which ancient history directs our attention, Egypt was the most distinguished by its numerous canals, which, according to Savary, amounted to 80, several of which are 20, 30, and 40 leagues in length. These served to receive and distribute the waters of the Nile, at the time of its inundation. Most of these are neglected, and, consequently, one-half of Egypt deprived of the means of its cultivation. The canals which convey the water to Cairo, to the province of Faioum, and to Alexandria, seemed to have engaged the chief attention of government. "An officer," says baron De Tott (Memoirs, vol. ii. p. 21, &c. Eng. ed.) "is appointed to watch this last, and hinder the Arabs of Bachria, who receive the superfluous waters of this canal, from turning them off before Alexandria be provided, or opening it before the time fixed, which would hinder the increase of the Nile. That which conveys the waters into Faioum is watched in like manner, and cannot be opened before that of Cairo, which is called the canal of Trajan." But the principal of these works was the Grand Canal, by which a communication was made between the Nile and the Red sea. This was begun, according to Herodotus (lib. ii. p. 181, &c. ed. Wesselingii.) by Necos, the son of Psammitichus, who desisted from the attempt on an answer from the oracle, after having lost 120,000 men in the enterprise. Strabo (lib. xvii. p. 1157. ed. Casaubon.) ascribes the commencement of it to Scopsiris, before the Trojan war. It was resumed and carried on by Darius, son of Hytaspes, who relinquished the work on the representation made to him by unskilful engineers, that the Red sea being higher than the land of Egypt, would overwhelm and drown the whole country. Diodorus Siculus (lib. i. p. 39. ed. Wesselingii.) gives the following account of this canal. "A canal of communication has been cut, which passes from the gulf of Pelusium to the Red Sea. It was begun by

Necos, the son of Psammetichus, and continued by Darius king of Persia; but left imperfect in consequence of the advice of some persons who asserted that it would lay Egypt under water, because the land was below the level of the Red sea. Ptolemy II., however, finished the undertaking, and constructed, in the most convenient part of the canal, a dam, or sluice, ingeniously contrived, which opened to give passage, and immediately closed again. Hence the river which discharges itself into the sea, near the city of Arsinoe, has received the name of Ptolemy." From this passage, says baron De Tott, it is plain, that the sluices still existed in the time of Diodorus. The entrance of the canal near Suez yet remains, and might easily be rendered navigable, without employing sluices or locks, as the difference of the level is very small, and without endangering Egypt with inundations. This part of the isthmus, says the baron, affords land very favourable for such an excavation, through the small interval of 12 leagues, which separates the Arabian gulf from the arm of the Nile which approaches it, and afterwards falls into the Mediterranean at Timb. Strabo adds (*ubi supra*) that this canal was afterwards cleaned by Trajan. Its width, being 100 cubits, of 22 inches to a cubit, was sufficient for admitting the passage of two galleys abreast; and its depth was such as to bear the largest vessels. Pliny, in his account of this canal, (*lib. vi. cap. 29.*), states its breadth at 100 feet, its depth at 40, and its length to the bitter fountains (near Arsinoe) at 57 miles. By means of this canal, the valuable commodities of India, Persia, Arabia, and the kingdoms on the coast of Africa, which were brought by shipping to the Red sea, were conveyed to the Nile; and thence distributed by the Mediterranean not only to Greece and Rome, but to all the surrounding nations, until the Portuguese discovered a passage to India by the Cape of Good Hope. It did not, however, long serve the useful purposes of commerce, which were at first expected. Merchants were dissatisfied with the delay occasioned by going to the very bottom of the gulf, and afterwards with the inland navigation of the canal, and that of the Nile, to Alexandria. They found it much more expeditious to unload at Berenice, near the coast of the Red sea (see *BERENICE*); and after three days' journey, to send their merchandise directly down to Alexandria. Accordingly, this canal was disused, and goods were conveyed from Berenice to the Nile by land; a mode of conveyance occasionally used at this day. Strabo and others have asserted, that this canal was again opened about the year 635, by Amru, governor or prefect of Egypt, under the caliph Omar, for the conveyance of the corn of Egypt to Arabia, which was then grievously distressed by a famine. Elmacin, or Al Makin, lays, that a new canal was opened for this purpose, and called by Amru the river of the emperor of the faithful; but it has been more generally supposed, that he only renewed the ancient canal, the navigation of which, towards the decline of the Roman empire, had been much neglected. The authors of the *Modern Universal History* (*vol. i. p. 333.*), discredit the relation of Elmacin and Eutychius; and allege that there never was any passage for vessels dug between the towns of Al Fostat, on the eastern bank of the Nile, and Al Kolzum or Colzum on the Red sea. The river, or rivulet, denominated by them the river of the emperor of the faithful, say these authors, was undoubtedly no other than the Amnis Trajanus of Ptolemy, or the Khalig, which annually supplies the city of Cairo, as well as the neighbouring country with water. For the present state of this canal, see *CAIRO*. They suppose, therefore, that, on the occasion now referred to, the caliph Omar ordered Amru to make the Khalig more navigable, by clearing it of the gravel or sand with which it was then

choaked up; and that, for this reason, it received the name of the river of the emperor of the faithful. Elmacin farther informs us, that the Alexandrian canal was stopped again, at the end next the Red sea, by the caliph Abu Jaafar, or Almanzor, in the year of the Hegira 150, A.D. 767. Some traces of this canal are still subsisting; and M. Boutier, in 1703, discovered that end of it, which rises out of the most easterly branch of the Nile. *Hist. Acad. Sc. for 1703, p. 110, &c.*

The canal of Alexandria, cut from the Nile to this city by Ptolemy, during the inundation of the Nile, receives its water at Lattf, opposite to Fouah, and has three bridges over it, of modern construction. Near the former, by the sea-side, is the entrance of the subterraneous aqueduct, that carries a supply of water for the Alexandrians into the cisterns, the arches of which supported the whole extent of the ancient city, but they are now incapable of being traced out. The mouth of this aqueduct is now blocked up; but when the water of the canal had arrived to a certain height, in consequence of the rise of the river, the principal magistrates of the city went in great ceremony to break down the dam. When the cisterns were full, it was again built up, and the water of the canal continued to fall into the sea at the old port. It was by this easy communication that merchandise was formerly conveyed through Egypt. The dangerous passage of the mouth of the Nile was thus avoided, as well as the perils of the sea. But beside furnishing the city with water, and facilitating its commerce, this canal, which passed along the upper part of the cultivated lands, on the left hand of the Nile, contributed very much to their fertility. In process of time it was shamefully neglected. However, it was cleaned by order of Bonaparte, in his irruption into Egypt, as far as Rhamania. See *ALEXANDRIA*.

Egypt is intersected in various directions by many other canals. Several of them issue from that arm of the Nile which runs to Damietta, and contribute to fertilize the province of Sharkia, which, making part of the isthmus of Suez, is the most considerable of Egypt, and the most capable of a great increase of cultivation. Others run through the Delta, and of these, says baron De Tott, many are navigable. The canal of Menouf communicates with the two branches of the Nile, 10 leagues below the angular point, called the "Belly of the cow." See *MENOUF*. The canal of Bahira proceeded from the lake Mœotis, near Alexandria, and having sent off branches which joined the western branch of the Nile at Eschim, Shabur, and Nadir, passed on to Upper Egypt. The other principal canals of Egypt will be mentioned in connection with the towns or districts to which they belong.

There is no country on the face of the globe that abounds more with canals and navigable rivers than CHINA: to which article we shall refer an account of its inland navigation. Hindoostan likewise furnishes instances at a remote period of the acknowledged importance and utility of canals. As the country between Delhi and the Panjab was scantily supplied with water, the emperor Feroze III., who died in 1388, undertook, says major Rennell (*Memoir, p. 71.*), the noble, as well as useful, task of supplying it better, and at the same time of applying the water, so furnished, to the purposes of navigation.

The immediate object of the canals, projected and executed by Feroze, for an account of which we refer to Rennell (*ubi supra*) seems to have been the junction of the Setlege and Jumnah rivers, through an interval of 240 geographical miles, and remotely that of the Indus and Ganges. If this grand design of Feroze had been completed, it must have ranked with the greatest works of this kind; "for we

should then have seen two capital rivers, which traverse a large part of Southern Asia, which enter the sea at the distance of 1500 British miles asunder, and which stretch out their arms, as it were, to meet each other, united by art: and those by nature to a third; so as to form an uninterrupted inland navigation from the frontiers of China to those of Persia." The country of Bengal is so intersected in various directions by the natural canals of the Ganges and Burranipooter rivers, together with their numerous branches, as to form the most complete and easy navigation that can be conceived: and it is supposed, that this inland navigation furnishes constant employment for 30,000 boatmen, who are employed in conveying by water through the kingdom of Bengal and its dependencies, all the salt and a large proportion of the food consumed by 10,000,000 people, and in transporting commercial exports and imports, probably to the amount of 2,000,000. sterling per annum.

The improvement of inland navigation engaged but little attention in Russia before the reign of Peter the Great. With him, after his return from Holland, where he had observed its useful effects, the construction of canals became a principal object. Of those projected and hastily executed by him, we may mention that of Cronstadt, that of Ladoga, that of Vishnei-Voloshok, and that for forming a communication between Moscow and the Don. For an account of the canal of Cronstadt, which was left unfinished by czar Peter, see CRONSTADT. The Ladoga canal was begun in 1718 by his order, and finished during the reign of the empress Anne. It was carried out first only as far as the Kibona, a rivulet which enters the lake to the east of Schlusfelburgh; but now reaches, without interruption, from the Volkof to the Neva. The length is $67\frac{1}{2}$ miles, and its breadth 70 feet; the mean depth of water in summer is seven, and in spring ten feet; it is supplied by the Volkof and eight rivulets. The barks enter through the sluices of the Volkof, and go out through those of Schlusfelburg. In 1778, four thousand nine hundred and twenty seven vessels passed through this canal. A scheme has been projected, and in part executed, for uniting the White Sea and the Baltic, and thus improving the commerce between Archangel and Petersburg, by forming a communication between the Ladoga and Beilo-Ozero to the Duna. The canal of Vishnei-Voloshok, forms a communication by water between Astracan and Petersburg, or between the Caspian and the Baltic. This canal was begun and completed under Peter the Great; but it has been considerably improved by the empress Catharine, so that vessels reach Petersburg in half the time which they formerly employed. In order to form an idea of the course of this inland navigation, a map of Russia should be consulted; and it will be seen, that the river Shlina forms the lake Mastino, which gives rise to the Maista; this, after a course of 234 miles falls into the lake Ilmen, from which issues the Volkof; and this, running 130 miles to the lake Ladoga, supplies the Neva; so that, in effect, the Shlina, the Maista, the Volkof, and the Neva, may be considered as the same river flowing into and through different lakes. By uniting, therefore, the Shlina, which communicates with the Baltic, with the Tvertza, which flows by the Volga into the Caspian, the canal of Vishnei-Voloshok completes the communication between these two seas. In autumn the navigation from Vishnei-Voloshok to Petersburg is performed in little more than a month; in summer in three weeks. In one year 3485 barks have passed through this canal.

The grand project of uniting the Caspian and the Baltic with the Black Sea, by the junction of the Don and Volga, was planned by Peter the Great. These two rivers approach each

other within the distance of 40 miles in the province of Astracan; and two rivulets, the Iloffa which falls into the Don, and the Camashinka falling into the Volga, are separated only by an interval of five miles. If these rivulets could be made navigable, and united by a canal, the Black Sea would be joined with the Caspian and Baltic. Repeated attempts have been made for this purpose, but they have hitherto failed. However, as the Volga and the Don are but 40 miles distant, and land carriage in this country is very cheap and easy, the advantages resulting from the projected canal would be scarcely equivalent to the expence of forming it. In 1802, a beautiful chart was published, exhibiting a view of all the canals in Russia, that have been formed between the White and Black Sea, and between the Baltic and the Caspian. The inland navigation is already carried through such an extent in Russia, that it is possible to convey goods by water 4472 miles from the frontiers of China to Petersburg, with an interruption only of about 60 miles; and from Astracan through a tract of 1434 miles. Cox's Travels in Poland, Russia, &c. vol. iii. Tooke's view of the Russian Empire, vol. i.

The first sovereign of Sweden, who duly appreciated the utility of inland navigation, was Gustavus Vasa. Having made Lodefe (now Gotheborg) a staple-town of trade, he conceived hopes, that in order to prevent the merchant-ships bound to Sweden from being obliged to sail through the Sound, the merchandize might, at some future period, be transported from thence to Stockholm, by means of the Wenner, Hiemar, and Mæler, when the rivers and lakes uniting with them should be rendered navigable. Eric XIV. desirous of executing his father's plans, directed a survey to be made of the waters communicating with those lakes, and plans to be formed for joining them by artificial canals. But the turbulence and misfortunes of his reign frustrated the accomplishment of his designs. The same object was kept in view by succeeding sovereigns. Charles IX. promoted it by the Carlsgraf canal, and Charles XI. by that of Arboga. Gustavus Adolphus wished to encourage the design, but could not find persons competently qualified to execute it: and Charles XI. was discouraged by the report of Dutch engineers, who declared it impracticable. Charles XII. however, approved the proposal of the celebrated engineer, Polhem, for rendering the cataracts of Trollhætta navigable, and for opening a communication, not only between Gotheborg and Stockholm, but also with the Wenner, the Vetter, and Nordkiöping, sufficient for the passage of large vessels. The execution of this plan was immediately begun by his order, and, after his death, revived by Adolphus Frederic. It comprehended three principal parts; viz. the junction of the Mæler and the Hiemar, of the Hiemar and Wenner, and of the Wenner with the German Ocean. The two lakes of the Mæler and Hiemar are united by the Ulvison, and the canal of Arboga. This canal (see ARBOGA) is, for the most part, of sufficient breadth to receive two barks abreast, and its lowest depth is eight Swedish feet. It is chiefly supplied with water from the lake Hiemar, which is 80 feet higher than its level; and this fall is broken by eight sluices. With a view of joining the Hiemar and Wenner, many schemes were proposed, but difficulties occurred which prevented the completion of them. The junction of the Wenner with the German Ocean has been attempted by the Carlsgraf canal, the canal of Trollhætta, and the sluices of Akerstram and Edet. The Carlsgraf canal, so called from Charles IX. who commenced it, connects the Wenner with that part of the Gotha, where it is first navigable. In 1758 a new sluice to supply the place of that of Polhem, carried away by the water, and of that

called Tefsin, found insufficient, was completed; and denominated the sluice of Gustavus. This superb work is a cut of 400 feet, partly perforated through the solid rocks, and consisting of two locks, each 200 feet long, and 36 broad; the sides being strongly faced with brick and stone. The greatest depth of water is 13, and the lowest six feet. This canal is commonly navigated by vessels of 80 tons burden. From the end of this canal to the village of Trolhætta, including an interval of five miles, the navigation of the Gotha is uninterrupted; but when it bursts at once into the cataracts of Trolhætta, called the "gulfs of hell," all farther navigation becomes impracticable through a space of about two miles. Here it is divided into four principal cataracts, separated by whirlpools and eddies, and descending through a perpendicular height of 100 feet. Nevertheless, an attempt has been made to form a canal through these cataracts. The first attempt, after much labour and expence, failed; and another plan was adopted. The length of the canal was to be 4700 feet, its breadth 36, and its depth in some parts above 50; and it was to consist of nine sluices; but the whole of the cut was to be excavated through a bed of red granite; and though it should not be condemned as impracticable, the difficulties attending it appear to be almost insuperable. After all, it has been doubted, whether the enormous expence attending the execution of it will be compensated by the advantages resulting from its completion. Gustavus III., soon after his accession, visited the works, and ordered all of them to be suspended, except the sluices of Gustavus and Aker. But, in order to facilitate the conveyance of merchandise from the districts bordering on the Wenner to Gotheborg, a wooden road has been constructed on the side of the river, from the beginning to the end of the cataracts. About a mile below the cataracts, the course of the Gotha is again interrupted by a fall, called Akerstrøm; and here a canal has been made through a rock, 182 feet long, including the sluice, 26 deep, and 36 broad. From Akerstrøm the river is clear to Gotheborg, excepting at Edet, where it is intercepted by a bed of rocks. On one side of these rocks another cut has been made, 600 feet long, 20 deep, and 18 broad. The iron and other merchandise are now transported across the lake to Wennerborg, through the Carlsgraf canal, and down the river Gotha to Trolhætta. At the cataracts they are unloaded, carried over the wooden road two miles to the end of the falls, again embarked, and passing through the Akerstrøm and Edet sluices, arrive without further impediment at Gotheborg. *Coxe's Travels*, vol. iv.

The principal canal of Denmark is that of Kiel. This canal was designed to complete the inland navigation, which, for the purpose of facilitating the communication between the Baltic and the German Ocean, is formed across the duchy of Holstein, and it unites with the river Eyder, which passes by Rendsburgh, and falls into the German Ocean at Tonningen. It begins about three miles N. of Kiel, at the mouth of the river Lewensawe, which heretofore separated Holstein from Sleswic, and will become a new boundary between these two duchies. The distance from its beginning to the east sluice at Rendsburgh is 27 English miles; but as the Eyder is navigable about 6½ miles above Rendsburgh, the cut necessary for completing the communication between the two seas is only 20½ miles. It was begun in 1777, and was opened in 1785. The perpendicular fall towards the Baltic is 25 feet six inches; that towards the ocean 23; and the vessels will be raised or let down by means of six sluices. The breadth of the cut is 100 feet at the top, and 54 at the bottom; the sluices are 27 feet broad and 100 feet long, and the lowest depth of water is 10 feet. Mer-

chantmen of about 120 tons burden will be able to navigate this canal. The utility of this important undertaking is indisputable. At present, even the smallest vessels, trading from any part of the Danish dominions in the Baltic to the Northern Sea, must make a circuit round the extremity of Jutland, and are liable to be detained by contrary winds. This navigation is so tedious, that goods shipped at Copenhagen for Hamburg are not unusually sent by sea only to Lubeck, and from thence by land. The object, says Mr. Coxe, of those who planned this canal, was to draw by Kiel into the Baltic, the commerce of Bremen, Hanover, and Westphalia, which is now carried down the Weser, and by Gluckstadt upon the Elbe, to Hamburg and Lubeck; and to facilitate the transport of merchandise from Holland and the North Sea to the ports of the Baltic. But the difficult navigation of the Eyder between Rendsburgh and Tonningen, occasioned by numerous shoals of shifting sands, will prevent the complete success of this canal. Ships sailing from the Baltic to English or French ports, will without doubt prefer the navigation round the Cattegat, with all its dangers and difficulties. The trade of Kiel, however, will at all events be greatly increased by this canal; but the principal depository of the merchandise will be at Rendsburgh. *Coxe's Travels*, vol. v.

The canals of Holland and Flanders are innumerable; and they serve the purpose of our public roads, so that the inhabitants may travel by means of them in their trekschuyts and barges, and convey commodities for consumption or exportation, from one part of the country to another, as occasion requires. An inhabitant of Rotterdam, it is said, may, by means of these canals, breakfast at Delft or the Hague, dine at Leyden, and sup at Amsterdam, or return home again before night. By them also a prodigious inland trade is carried on between Holland, France, Flanders, and Germany. When the canals are frozen over, they travel on them with skaits, and perform long journies in a very short time, while heavy burdens are conveyed in carts and sledges, which are then as much used on the canals as in our streets. The profits which have accrued from these canals have been immense; and their amount almost exceeds belief. It is said, that they have yielded more than 250,000*l.* for about 40 miles of inland navigation. The canals of Holland are generally 60 feet wide, and six deep, and are kept cleansed; the mud, as manure, being very profitable. They are generally level, and need no locks; and they are commonly elevated above the country for the purpose of carrying off the waters, which in winter inundates the land. In the province of Delftland, not more than 60 miles long, 200 wind-mills are employed in spring to raise the water into the canals. On the dams or banks by which they are bordered, and which are kept in repair at a very considerable expence, depends the security of the country from inundation. The canals of Flanders, ever since their trade has declined, and the cities erected on their banks have decayed, have been very much neglected. They indicate, however, the former flourishing and prosperous state of the country. So early as the 12th century, large canals were cut; and they answered the purpose of inland commerce as well as of draining the land. The spacious canal of Brussels, begun in 1531, and completed in 1560, extends from this city to the Scheldt, which opens a communication with Holland, and by the canals of Flanders with the ocean. The canals of the other Dutch and Flemish towns will be mentioned under their respective articles.

France has from a very distant period exercised its ingenuity and activity in the construction of canals for inland navigation. We must content ourselves with a cursory

mention of some of the principal. The canal of Briare, called also the canal of Burgundy, was begun under Henry IV. and finished in the reign of Louis XIII. It opens a communication between the Loire and the Seine, and then between Paris and the western provinces. Commencing at the Loire near Briare, it passes to Montargis, joins the canal of Orleans, which was begun in 1675, and has 20 sluices, and falls into the Seine near Fontainebleau. It has 42 locks and sluices; and is of great use in inland commerce. The canal of Picardy connects the river Somme with the Oise; and beginning at St. Quentin, joins the Oise, and affords a ready conveyance to Paris for the grain of Picardy, the sea-coal, wood, butter, copper, and spices from the northern provinces of the kingdom, and from Holland. The most considerable work of this kind is the canal of Languedoc, called the canal of the two seas, which forms a junction between the Ocean and the Mediterranean. It was first projected under Francis I., but begun in 1666, and finished in 1681, under Louis XIV., during the ministry of Colbert, and by the skill of Riquet, the engineer. It established a ready communication between the two fertile provinces of Guienne and Languedoc, and extends from Catce in the bay of Languedoc, to the Garonne below Thoulouse, being provided at proper intervals with 114 locks and sluices. In some places it is conveyed by aqueducts over bridges, under which other rivers pursue their course. Near the town of Beziers, it was conveyed under a mountain by a tunnel, then thought singular and extraordinary, but now common, 720 feet in length and lined with free stone. At St. Ferriol it derives a supply of water from a reservoir containing 595 acres. Its breadth is 144 feet, including towing-paths; it is six feet deep, and its length 64 French leagues, or about 180 miles. The expense of its construction was about 540,000*l.*, defrayed partly by the king, and partly by the province of Languedoc. On the reduction of the army and navy in 1782, after the conclusion of the American war, the disbanded soldiers and seamen were employed in the construction of three navigable canals; viz. one, called the canal of Dehune, extending from Chalon-sur-Saone to the town of Dijon on the Loire, through an interval of 21 leagues, and forming a junction with the Saone and the Rhone: a second, called the canal of Burgundy, reaching from St. Jean-de-l'Aune to the village of Roch, between St. Florentine and Joigny, through a space of 52 leagues, and opening a communication between the Saone, the Rhine, the Yonne, and the Seine; and a third, called the canal of Neuf-Brissac, which commences at the village of St. Symphorin, on the Saone, and passing the city of Besançon, is continued below Strasbourg, forming a junction of the Saone with the Rhone, and of the Ill with the Rhine. By these canals goods may be conveyed at a cheap rate from Marseilles, the Mediterranean, Italy, and Switzerland, to the bay of Biscay and the Ocean, and also to Holland and Germany, as well as to Flanders and the Austrian Netherlands; and during any future war with England, France will be able to supply, by these canals, her dock-yards at Marseilles and Toulon, and also her grand arsenal and dock-yards at Breil and Rochfort, with all sorts of commodities from the Baltic, without hazarding a voyage by sea. It would be endless to enumerate all the canals, projected or actually executed in France, and forming an easy intercourse between the different districts of this extensive country. A survey has lately, in 1802, been made of the little river Buzeg or Bureg, with a view of its being brought to Paris in the same manner as the New River is brought to London, and of being laid into the streets and houses by pipes, fire-plugs, and engines, for the purpose of cleansing the streets,

as well as accommodating the houses. Phillips's *Inland Navigation*, p. 75. 8vo.

Spain has not been altogether inattentive to the improvements likely to result from inland navigation. At former periods it has been often proposed to dig a canal through the isthmus of Darien, from Panama to Nombre de Dios, and thus to make a ready communication between the Atlantic and the South Seas, and to open a straight passage to China and the East Indies. The project, however, has been considered as chimerical, and treated with ridicule. The improvements meditated at home are of much greater importance: but though the inland navigations of Spain have been commenced upon principles both of grandeur and utility, they have been suffered to languish through the want of resources, and the tardy measures of the court. The great canal of Arragon afforded, in 1785, some hopes; but it seems to remain in an imperfect state. Two branches, however, are completed: those of Tautre, and the imperial canal, both of which begin at Navarre and terminate in the river Ebro, and they have already proved sources of industry to all the districts through which they flow, and rendered the fields fertile. One of these canals is conducted over the valley of Riojalon, by an aqueduct 710 fathoms in length, and 17 feet thick at the basin. Another canal called the canal of Castile was projected to begin at Segovia, about 40 miles N. of Madrid, and to extend to the bay of Biscay, through a distance of 140 leagues. This canal is 56 feet wide at the top, 20 feet at the bottom, and nine feet deep, but the completion of it will require many years. The canal of Guadarama was planned in 1784, and being conducted with spirit, is probably now completed. It was to commence at the foot of the mountains of Guadarama, near the Ekeurial, and to proceed to join the Tagus, afterwards the Guadiana, and terminate at the Guadalquivir, above Anduxar. Another canal was also begun to join the river Manzanares to the Tagus; but the work was suspended. The canal of Murcia was found, after its commencement, to be impracticable. Phillips's *Inland Navigation*, p. 75, &c.

The Americans possess a country capable of great and easy improvement by internal navigation. To this object they are not inattentive. For an account of their projects, and actual progress in this business, we must refer to Phillips's *Inland Navigation*, p. 571, &c., or to the Journals of Mr. Elkanah Watson.

CANALS, the British; from the great influence which they appear to have had, among other causes, during the last half century, in promoting the rapid increase of our commercial greatness as a nation, have induced us to lay before our readers a very full account, not only of the present existing canals, but of the principles and practice of canal making, in the united kingdoms. As very few of the English, Welch, Scotch, and Irish rivers, are of sufficient magnitude, and free from shoals, to answer the purposes of navigation far into the country from the sea, without the aid of art, conducted upon similar principles to those used in canal-making; and as nearly all our canals connect with the navigable rivers, and act in some measure, as extensions of them further into the country, we have found it expedient to include under this article, whatever we have been able to collect on the subject of the *Inland Navigation of the United Kingdom*.

That the navigation of our rivers, by ships or smaller vessels has long been an object of considerable importance, will appear from *magna charta*, which has made a special provision in the 23d chapter, for the putting down of weirs and other obstructions in the rivers of England; and from stat. 25 Edw. III. c. 4. which sets forth, that "whereas the com-

mon passages of boats and ships in the great rivers of England, be oftentimes annoyed by inhauling gores, weres, flakes, &c. in great damage of the people: it is established, the same shall be cut and utterly pulled down, without being renewed, and that writs be sent to the sheriffs to do execution." After two other unsuccessful attempts by statutes in the succeeding reigns, to prevent the free navigation of the rivers from being obstructed by individuals, intent upon fishing, embanking land, or building mills, bridges, or making fords, the statute of the 4th of Henry I. chap. 12, appointed special commissioners for carrying the above statutes into effect; whose powers were continued and enforced by two other acts, prior to the 23d of Henry VIII. chap. 5, which being entitled, "The Bill of Sewers with a proviso," appointed a general commission of sewers, with large powers that are still in force and acted upon, for making laws and ordinances, and compelling obedience thereto, for the "removing and preventing of impediments and annoyances on rivers, streams, and floods, whereby the passage of ships and boats might be letted or interrupted." And by the statute of Edward VI. chap. 8, the last mentioned and former statutes were confirmed and made perpetual. During the above period, several other statutes were also made, for removing obstructions in particular rivers, of some of which we shall have occasion to speak when we come to mention those rivers.

The general laws of the land proving so very ineffectual for protecting internal navigation from the encroachments of individuals and the effects of neglect, this probably suggested the propriety of those particular grants or statutes which we find enabling corporations, and in some instances individuals, to take particular rivers under their charge, and to receive tolls or dues from the vessels navigating within their particular district. In process of time, as population increased, and the advantages of water carriage became more apparent, further grants and acts of parliament were made, authorising companies or individuals to extend the navigation on certain rivers further into the country, generally to reach some city or great town; these acts, some of which we shall particularize hereafter, generally enabled the parties to deepen, and in some instances to straiten the course of their rivers, to embank them where too wide, to erect jetties and sluices, to make flashes for surmounting the shallows or rapids, and in later times to erect pound-locks for gaining the ascent to the different mill-dams upon the river. But the constant tendency of rivers, especially rapid ones, to call up banks of sand or gravel in particular places, their deficiency of water in times of drought, and superabundance in times of flood, the ravaging effects of these last in destroying the works erected for the use of the navigation; as happened on the river *Avon* between Christchurch and Salisbury; on the river *Stour*, between the Severn and Stourbridge; on the river *Cadder*, between Wakefield and Eland, and on several others which might be mentioned; the great labour and difficulty of towing or dragging vessels against the stream, especially where there was not a towing-path for horses, near to the channel of the river, and yet not subject to be overflowed and rendered useless in time of floods; the very lengthened course of most rivers, arising from their serpentine, and, in some instances, varying channel, was not also among the smallest of the difficulties attending them: these, at length, suggested the propriety of leaving the bed of the rivers in some instances for a new cut for the navigation across a neck of land, with a pound-lock at its lower extremity. As these side cuts and pound-locks were increased in number, to shorten the course of the rivers, their superior advantages be-

came so apparent, that a company of gentlemen and merchants, who had in 1755 obtained an act of parliament authorising them to make *Sankey Brook* navigable from the Mersey river to near St. Hellins, in Lancashire, with the powers at that time usual in navigation acts, for the purchasing of land and other things necessary for the intended navigation, at a fair estimate to be made by commissioners named in the acts they determined, after mature deliberation, to avoid the bed or channel of the brook altogether, and to make one entire new cut or canal, as near as convenient to the bed of the river, with locks thereon, in such places as the fall of the ground should render necessary; and this canal they accordingly effected about the year 1760, supplying its highest pound or level with water, by a cut or sinder from the Brook. Thus navigable canals had their rise in England; but, a less fortunate set of gentlemen, who under the power of an act obtained in the year 1730, for making the river *Stroudwater* navigable, from the river Severn to near the town of Stroud, although the act empowered them "to make as many new cuts as they may judge proper, and of what length and breadth they shall think convenient;" yet when they had, about the year 1774, determined upon following the example of the *Sankey* proprietors, and in imitation of the duke of *Bridgewater's*, and several other canals, which had then been executed or were begun; by cutting a canal on the side of the *Stroudwater* river, they were stopped by an expensive law-suit, carried on by certain mill and land-owners in the neighbourhood: whereby the distinction between the river navigation acts, and canal acts was established by the Court of Exchequer, before which the case came to be argued.

About the year 1757, the *Duke of Bridgewater*, acquainted fully, no doubt, with what had been near 80 years before effected, on the canal of Languedoc, in the South of France, and since in different parts of the Continent, conceived the idea of a canal for the purpose of conveying coals from his estate at Worsley in Lancashire, to Salford near Manchester. His grace, profiting as no doubt he did, by the works of that great French engineer, *Francis Riquet*, and by the advice of that great natural and self-taught genius *James Brindley*, whom his grace called off, about the year 1758, from his employment as a mill-wright and engine-maker in this country, to perfect, and carry into execution, the great and important schemes which he had projected, and for which he proposed and brought into parliament the first act, with powers adequate to the great and extraordinary undertaking, of cutting a canal of several miles in length, not in the direction of any river or stream of water, but crossing the course of several brooks, roads, &c. and through the lands of a vast number of different persons, all of whom were to be fully compensated, though deprived of the power of withholding their lands or waters, or in any way obstructing the design. In these respects, the *Duke of Bridgewater* has not improperly been called the father of canals in England, while his engineer, the late *Mr. Brindley*, by his masterly performances on the *Duke of Bridgewater's* canal, altered and extended as the scheme thereof was, by three subsequent acts of parliament, has secured to himself, and well it should seem, from a comparison of the great features, and minutiae of execution in this the first canal, with most others in this country, even of the latest construction, long continue to hold, that rank among the English engineers, to which *M. Riquet* seems entitled among foreigners.

The course, thus happily opened by the *Duke of Bridgewater*, was quickly followed by new sets of adventurers, who were seen applying to parliament in almost every session, for powers to raise a joint stock on transferrable shares, and

to make and maintain canals in most parts of the kingdom, many of which have been long completed, as our subsequent account of them will shew, and have contributed in a most eminent degree to the improvement of the country, as well as to the enriching of the individuals concerned in a great number of instances; in the laudable zeal of adventurers to extend, and of the people of great towns and proprietors of mines and great manufactories to receive, the benefits of inland navigation; numerous schemes have been adopted, where from the actual scarcity of water, or its previous appropriation to mills, a canal with locks was impracticable. One of the first of these schemes for dispensing with locks, was that of *Mr. Bridger*, about the year 1759, upon the *Stroud-water* river before mentioned, where the cargoes of the boats were disposed in a number of boxes or frames, just adapted to the size of the boats; which boxes of goods were drawn up by cranes to be lodged in other boats on the higher level, and the reverse in descending; which method was afterwards

successfully practised on *Bridgewater's* canal at *Worsley*, at *Briecley Hill* on the *Shropshire* canal, and other places. The next mode seems to have been adopted by *Mr. Davis Drekart*, near the *Tyrone* collieries on the intended connection with *Blackwater* navigation in Ireland, about the year 1776; and afterwards by *Mr. William Reynolds* on the *Kesley* canal, where the boats were dragged up or let down inclined planes, not very different from the rolling bridges, long before in use in Holland and Flanders.

The necessity of an expeditious and cheap mode of conveying coals from the pits to the keels or ships, had, as early as the year 1680, introduced the use of wooden railways, for the waggons to move upon, between the *Tyne* river and some of the principal pits, and these by degrees became extended to a great number of other coal-works. Since the more general introduction of cast iron, and its cheaper conveyance by means of canals, iron rails have been substituted in the place of the wooden ones before mentioned; and the use of inclined planes, or parts of the railway having a much greater declivity or slope than it is practicable to drag carriages up by means of horses, has become very frequent in parts where the rise of the ground required it, machinery being on these inclined planes adopted to supply the place of horses.

Several years ago, an act of parliament was obtained by *Homfray, Hill, and Co.* for an iron rail-way, or tram-road from *Cardiff* to *Merthyr*, by the side of, and as a rival scheme of the *Glumorgan-shire* canal, for 9 miles or more in length; since which, several other acts have been passed for rail-ways, and several of them executed, to the great benefit of the country, and the companies who constructed them; it has also become common within the same period, to authorise canal companies to construct rail-ways, as collateral branches from their canal, to mines or other great works or to large towns within certain distances of such canals; by which their benefits have been amazingly extended: most of the latter acts have also authorised the adoption of rail-ways, of inclined planes, or of any of the expedients above-mentioned, or others as substitutes for locks, in such parts thereof, as are not readily to be supplied with water, adequate to the waste which locks occasion. So many of these compound schemes for lessening the expence of carriage have been already executed, or are in hand, that we have found ourselves compelled, in order to present our readers with a connected and useful view of the subject, to include what we have to say on the subject of *rail-ways*, in the present article, as well as treat therein of *navigable rivers*, for the reasons before stated.

Great Britain as well as every other island, and even a

continent taken as a whole, has a range of high land passing nearly its whole length, which divides the springs and rain waters that fall to the opposite coasts: we shall call this range dividing the eastern and western rivers of Britain the *grand ridge*, and shall in our accounts distinguish on which side, or how each canal is situate, in respect thereof: and here it will be proper to remark, that no less than 22 of our canals now do or are intended to pass this grand ridge, forming as many navigable connections between the rivers of the east and west seas! these are the *Inverness and Fort-William*, *Forth and Clyde*, in Scotland; the *Leeds and Liverpool*, *Rochdale*, *Huddersfield*, *Trent and Mersey*, *Staffordshire and Worcestershire*, *Wyrley and Essington*, *Birmingham*, *Dudley*, *Worcester and Birmingham*, *Stratford*, *Warwick and Birmingham*, *Coventry*, *Grand Junction*, *Oxford*, *Thames and Severn*, *Willis and Perks*, *Kennet and Avon*, *Dorset and Somerset*, *Grand Western*, and *Bude and Launceston*, in England: and what is not a little remarkable is, that the *Dudley* canal crosses this grand ridge twice, the two ends being on the eastern side, and the middle part on the western side thereof; the *Kennet* and *Avon* crosses the eastern and western branches, into which it divides on the Chalk Hills, west of *Marlborough*, by which parts of this canal are in the drainage of the west, the south, and the east seas! the *Coventry* canal also, by means of its *Bedworth* branch, crosses the grand ridge twice. The populous and remarkable town of *Birmingham* is situate on high ground, near to the grand ridge, and has six canals branching off in different directions, either immediately therefrom or at no great distance, and what is singular, owing to a loop, or sudden bend of the ridge at this place, no less than five of them traverse the grand ridge, either by means of tunnels or deep-cutting.

When we propose to lay before our readers a more full and methodical account than has been given of the British canals, on which large sums of money have been expended by individuals, and from which important and lasting benefits have been derived by the inhabitants in their immediate vicinity and by the kingdom at large; it is needless to state any formal arguments, in answer to the millaken objections, which were 40 years ago commonly circulated, whenever a new canal was in contemplation; such as their walling of land, producing noxious and humid vapours, destroying the breed of our draught horses, lessening the coaling trade and the nursery of seamen, injuring old mines and established works by enabling new ones to be opened, introducing pilfering workmen and boatmen into the country, &c. &c. To the more serious objections, arising from the cutting of estates and fields in two; the taking of water from mills, &c.; interfering with former navigations by canals or rivers, and even with roads, on which, in some instances, large sums have been expended, and remain not reimbursed; to these and many others, we shall have the best opportunity of replying, when we come to mention the equitable provisions which individuals have proposed, and the legislature have in so many instances enforced, for securing to every one an adequate compensation for what he is called upon to give up.

General arguments in favour of canals are superseded by the rapidly improving and thriving state of the several cities, towns, and villages, and of the agriculture also near to most of the canals of the kingdom, the immense number of mines of coal, iron, limestone, &c. and great works of every kind to which they have been conducted, and to which a large portion of them owe their rise, are their best recommendation.

Justice requires our acknowledging the assistance we have received in compiling this account, from the *General History of Inland Navigation* by *John Phillips*, from the three

numbers which are published of *John Cary's Navigable Canals of Great Britain*, from *C. Smith's*, *George Allen's*, and *Jaurie and Whittle's* maps of the canals, &c.; from *J. Cary's* large map of *England, Wales, and part of Scotland*; from *Robert Fulton's Treatise on Canal Navigation*, from *William Chapman's Observations on Canal Navigation*, from *Joseph Plymley's Agricultural Report of Shropshire*, from *Zach. Allnutt's Considerations on the Navigation of the Thames*; from *Thomas Badelade's*, and from *Nathl. Kinderley's Accounts of the Navigation of Lynn and Wisbech*, &c. from the *Agricultural and Monthly Magazines*, from *Dr. Anderson's Recreations*, from the *Annual Register*, from *Thomas Telford's Reports on the Caledonian Canal*, &c.; and from the writings of others, to whom we particularly refer.

To *Mr. William Smith*, engineer, of Buckingham-street, London, we are indebted for many valuable hints and information given on many points, as we are also to *Mr. Benjamin Bevan*, engineer, of Leighton Buzard, Beds.

When it is proposed to form any canal, the choice of a skilful and experienced engineer is an object of primary consideration. Without due attention to this object, many impracticable projects may be adopted, and large sums of money may be expended without accomplishing any important and useful purpose. In suggesting the principal qualifications that are necessary for rendering persons competent to be consulted or employed in undertakings of this kind, we shall merely specify some of those that have in an eminent degree distinguished, or that still no less conspicuously distinguish several of our own countrymen. A skilful engineer should undoubtedly possess a considerable degree of mathematical knowledge. Calculations, of which some are of the most abstruse and laborious kind, will frequently occur; and he should, therefore, be well acquainted with the principles on which all calculations are founded, and by which they are to be rightly applied in practice. An engineer should also have studied the elements of most or all of the sciences, immediately connected with his profession; and he should particularly excel in an acquaintance with the various branches of mechanics, both theoretical and practical. His knowledge should comprehend whatever has been written or done by other engineers, and he should have information in every department of his office from an accurate examination of the most considerable works that have been executed in all the various circumstances that are likely to occur. It is necessary, that he should be a ready and correct, if not a finished, draughtsman. He should also be conversant with the general principles of trade and commerce; with the various operations and improvements in agriculture; with the interests and connection of the different owners and occupiers of land, houses, mills, &c.; and with all the general laws and decisions of courts, pertaining to the objects connected with his profession. By an extensive acquaintance with the disposition, inclination, and thickness of the various strata of matter, which compose the soil or land of the British islands, he will be able to avoid many errors incident to those who are destitute of this knowledge, and to have the course and causes of springs, to which it leads. As the last, though not the least, of these qualifications of an engineer, which we shall enumerate, we shall add, that he should be a man of strict integrity. If, at this day, the affairs of any canal company should be entrusted to persons deficient in all or the greater part of the qualifications above enumerated, the managers of such a company will thus incur a serious responsibility to the proprietors and to the public. In this connection we think it right to mention an institution that had its rise in the year 1771, viz. "the Society of Civil Engineers," as admirably calculated to ex-

tend the influence of our present and more experienced engineers, and to bring forward to public notice others, who, in the course of events, are destined to second them. For further particulars relating to this society, we refer to the preface of the first volume of *Smeaton's Reports*, *Nicholson's Journal* 4to. vol. ii. and the article *SOCIETY of Civil Engineers*.

A proper engineer being fixed upon, the adventurers should not tie him down too closely, by restrictions as to time, but allow him leisure to consider, digest, and revise again and again, the different projects and ways, which will naturally in most instances present themselves to him in an extensive and thorough investigation. The engineer should be allowed to chuse and employ the most competent assistants, and to call in and occasionally to consult the opinions of eminent or practical men, as land-surveyors, agents of the neighbouring landed property, the principal and most expert commercial men of the district, and who are best acquainted with its trade and wants, any eminent miners, &c. &c.; and such men the engineer should be authorized liberally, and at once to remunerate for their services and intelligence.

Previous to the beginning of any minute survey or system of levelling, the engineer ought to visit personally, and endeavour to make a just estimate, and preserve memorandums of all the objects within the district under consideration; as of the trade and importance of all the towns likely to be affected by the undertaking, of all mines of coal, iron, &c. quarries of lime-stone, free-stone, slate, &c. or the situation where such can be found, of all manufactories of heavy and cumbrous goods, and other extensive works; and generally of every thing likely to furnish tonnage for a canal. By this time, if the district under consideration be of very considerable length, more than one, and perhaps several, different routes for the proposed canal have presented themselves: and it will be proper, while the engineer's assistants are carrying levels (using good spirit levels with telescopic sights) along each, and making rough sections of the ground, or brook or river along each line, himself to visit and pass along each of these, noting and weighing more particularly the principal difficulties which present themselves in each route, as summits or hills to be passed, or tunnelled through, valleys to be embanked across, with aqueducts over rivers or brooks, the greater or less plentiful supply of water, particularly at the summit levels, and how far the springs and streams of water are at present appropriated or essential to mills or gentlemen's pleasurable purposes, or to irrigation, or the land occupied by parks, turnpike roads, &c. The advantages of each route should also be as carefully noted; as the shortness of distance, connection with great towns, mines and works either on the line or by short and practicable side cuts or branches, the smallest number of locks, bridges, culverts, &c. In weighing all these circumstances, in order to determine on the most advisable line, it should never be lost sight of, that a canal is altogether a mercantile speculation, and cheapness of conveyance is the grand desideratum thereof: where, therefore, but few, if any, great towns, works, or mines are found upon a proposed line, and the principal object is to form a connection between the canals of a district more fortunately circumstanced in these respects, and the metropolis, or a great town, as in the case of the *Grand Junction* canal lately completed, it is evident, that much ought to be done to obtain the shortest route that is practicable: if, on the contrary, the district under consideration has great towns, mines of coal, or great works distributed about it, some miles in the total distance may be properly allowed, and a more circuitous route adopted, to

embrace as many as possible of these objects, particularly coal-works; for it has been remarked, that the carriage of coals gives rise to the principal revenues of most canals; and some have even contended, that no canal can answer to the proprietors unless the carriage of coals be its principal object: there are, doubtless, some exceptions to this rule. It may be concluded, upon the whole, that no canal can be completed and brought into use, but the inhabitants and the agriculture of the district will shortly feel great benefit from it, whatever may be the result to the proprietors; yet in the stage of the business of which we are treating, it is the peculiar duty of the engineer to study the interest, and bring forward the probable advantages of the proprietors, fairly and without exaggeration, in order that the subscription may fill, and the work be enabled to proceed. Before determining upon the route of a canal, its connection with the neighbouring canals or river-navigations should be well considered, and the engineer should inform himself accurately of the quantum of benefit or injury likely to result to each of such existing navigations by the effecting of the new one, or how far their rivalry, or that of any other scheme which may at the time be in agitation, is likely to effect the one he is employed upon; in all the practicable routes, which present themselves for the new canal.

The most eligible route for the canal being settled in the engineer's mind, he will then proceed to make a rough calculation of the quantity of goods of each different kind, which may be expected to pass upon the line in a given time; he will also examine all the canals and rivers which the proposed canal is to connect with, and ascertain the widths and depths thereof, the sizes of their locks, and of the vessels usually navigating them. The engineer will now be able, well considering the nature of the ground the canal is to pass over, to determine on the most proper dimensions for the intended canal, and whether the probable supply of water renders it practicable to effect the rises and falls by the ordinary mode of locks, or whether inclined planes, or any other of the expedients which we shall more particularly enumerate hereafter, should be adopted: or even, whether a rail-way, in whole or in part, may not be preferable to a canal. The mind of the engineer will properly be exercised upon these questions, before a more minute and expensive survey and planning of any particular line are entered upon; because, the line, though passing through the same tract of country, will generally require to be conducted in a very different place for great lengths together, according to the size of the proposed canal; and inclined planes, or a rail-way in whole or in part, will introduce a still greater diversity in the routes that ought, under the different circumstances, to be pursued.

Robert Fulton, in his 4to. Treatise on Canal Navigation, published at London in 1796; *William Chapman*, in his 4to. Observations on the various Systems of Canal Navigation, London, 1797; *Thomas Telford*, in J. Plymley's 8vo. General View of the Agriculture of Shropshire, London, 1803; *Edmund Leach*, *Dr. James Anderson*, and others in different works, have recommended and enforced, upon principles more or less general and true in their application, a variety of schemes and methods of conveyance, by small canals, inclined planes, rail-ways, &c. of which we shall take notice under their proper heads, and of which the engineer will of course avail himself, as far as they appear applicable; as well as of any other inventions, which his own ingenuity or that of others may supply. Long levels may, in some instances, be obtained, without inordinate expence; and will often prove of great utility, in the saving of the time and

trouble of passing locks in the neighbourhood of great towns, as in the cases of Coventry, which has the benefit of more than 73 miles of level navigation on the *Coventry, Ashby de la Zouch*, and *Oxford* canals; and of Manchester, which has 70 miles of level water by *Bridge-water's*, and *Mersey and Trent* canals, including 12 miles in the tunnel to the *duke of Bridge-water's* coal-works in Worsley Hill: Birmingham has 43 miles of still water, by means of the old *Birmingham*, the *Worcester and Birmingham*, the *Dudley* and the *Stratford* canals; and this upon so high a level, that the three last canals cross the grand ridge in that space: Lancaster and Preston have 42½ miles of level on the *Lancaster* canal; Wolverhampton enjoys the benefit of a level 40 miles in length, on the old *Birmingham*, and *Wyrley and Essington* canals; Liverpool has 28 miles of level on the *Leeds and Liverpool*, and Blackburn, 24 miles upon the same canal; Basingstoke has 22 miles upon the *Basingstoke* canal; Whitechurch 21 miles on the *Ellesmere*; Devizes 20 miles upon the *Kennet and Avon*; Bottesford 20 miles upon the *Grantham*; London enjoys the benefit of about 19 miles of level to Paddington, upon the *Grand Junction* canal; Glasgow 18 miles on the *Forth and Clyde*; Gloucester is to have 18 miles upon the *Gloucester and Berkeley*; Shrewsbury has 15½ miles on the *Ellesmere*; Stainesforth 13 miles on the *Stainforth and Keadby*; Abergavenny 14 miles on the *Brecknock and Abergavenny*; Market Harborough 13½ miles on the *Leicestershire and Northamptonshire Union*; Shrewsbury 11½ miles on the *Shrewsbury*; and Cromford 11 miles of level on the *Cremford* canal. Another benefit will sometimes occur from long levels, by the bringing of all, or of a considerable number of the locks near together, as at Runcorn on *Bridge-water's* canal, by which they are more effectually looked after and kept in repair. Should it be necessary to return the water let down by the lockage, again into the higher pound by the power of engines, as is done on the old *Birmingham*, the *Barnsley*, and many other canals, the having of considerable falls in one place will be of material consequence; but still more so if inclined planes are to be used instead of locks, as on the *Shropshire*, *Shrewsbury*, and *Ketley* canals. In conducting the line of a canal, it will always be advisable, if other circumstances will permit, to bring two or more locks near together, and to erect a lock-house for the residence of a careful and proper person upon the spot, to look after and assist the bargemen in working the locks; where this had not been attended to upon some canals, but single locks were placed at great distances from each other, the company have, from experience of the damage such locks sustain, found it necessary to employ great numbers of lock-keepers, and often to build houses for the superintendence of single locks. Mr. *Chapman*, who appears to have well weighed the question, whether large or small canals ought to be adopted under different circumstances, observes, "that the system of small canals is particularly eligible in all countries where lime-stone, coal, iron-ore, lead, and other ponderous articles, not liable to damage from being wet, or likely to be stolen, are the objects chiefly to be attended to; and where the declivity of the country runs transversely to the course of the canal, which will generally be the case along the sides of mountains, at an elevation above the irregular ground at their feet. In those situations, the great falls or inclined planes may be made at the forks of rivers, so that the upper levels may branch up both the vales, and thus give the most extended communication. A situation suited for those canals will often be found in countries that are not absolutely mountainous, but where the ground regularly declines towards the vales of large rivers." The principles for which Mr. *Leach* has so strenuously contended, of re-

versing the usual order of beginning navigations at the lowest points or the sea, and extending them up the valleys towards the summits, and, instead thereof, beginning near the summit or source of the water, and continuing the level till the greatest practicable falls are obtained for inclined planes, would, unless the most enormous expences were incurred for tunnels, deep-cutting, and embankments, prove too crooked and circuitous for a ready conveyance, as happened on the *Bude and Launceston* canal, which was proposed to pursue a serpentine course of 81 miles, between two places whose direct distance is no more than 28 miles! The long level of the *Oxford* canal, at its northern end, of which we have spoken above, appears among the most crooked of those canals which have been executed, and is particularly ill adapted, to the great thoroughfare or communication which it forms with other canals. Canals which are to form an immediate connection between the sea or tide-way at different places, as the *Inverness and Fort William*, *Grinan, Forth and Clyde*, the *Isle of Dogs*, and the *Gloucester and Berkeley*, must be of large dimensions, or the principal advantages of such a communication would be unattainable; in like manner, the communications between the sea, and docks or harbours, will some of them require to be of still larger dimensions, as the *Grimsby, Ulverston, Dee* new channel, &c. A system compounded of *water-levels*, or lengths of canal on different levels without communication by locks, may sometimes be found advisable, as on the *Shropshire, Shrewsbury, Kestley, Leicester*, &c. The advantages of being able to conduct a canal, in many instances, upon water-tight strata, instead of rocky or porous soils, and perhaps without losing sight of any of the other important considerations mentioned, are sufficiently great to induce engineers to become acquainted with the arrangement and particulars of the *strata* within their district, by a minute and careful examination, or to call in the assistance of those best informed on such points. We have purposely omitted, till now, to mention the consideration of the value or quality of land to be purchased for the use of the proposed canal by different routes; convinced that some late canals have been materially injured by the narrowmindedness of those who would avail themselves of cutting through common or low-priced land: even the general consideration of expence, in the works of a proposed canal, should hold but a subordinate place in the mind of an engineer in the present stage of the business, because contracted views in this respect may frustrate the attainment of a great portion of the benefits to be expected; and it cannot be doubted that any scheme of conveyance will best answer to the adventurers and the public, when conducted upon the principles most adapted to the case, let the expence be what it may; and fortunately, the commercial and public spirit, aided by the means of individuals collectively in this country, has long shewn itself equal to any enterprize however bold, where advantages can be shewn materially to preponderate.

In the particular survey of the line proposed, all the knowledge of the most expert and competent engineers, with the most able assistants, will be requisite. The rough section of the proposed line, before taken, will enable the engineer to see the places of the heights and breadths of the various summits, or ranges of high land that are to be passed, and whether any two or more adjacent ones can be connected by a long summit level, without deserting any considerable town or point of trade, which will diminish the difficulties of supplying the canal with water, as every such junction of summits preserves the water of two lockages, besides presenting to many more points at which the canal can be supplied with water, from springs and rivulets above its level, or where, in less favour-

able situations, the same can be collected in a lower level to be pumped up. The extremities of the principal summit or summits being thus nearly settled, it will next be inquired, how far it is practicable and advisable to reduce the height of the same by deep-cutting or by tunnelling, or both of them. The advisable height of the summit-level of the canal being settled, if water is not in sufficient plenty, a minute survey of both sides of the range, or ridge which is to be passed, and of all its connecting heights, for a considerable distance on each side of the line, should be made by tracing the proposed summit-level along all the sides of the hills, particularly noting all the springs or rivulets which rise above and cross this line; and all such streams of water should be accurately gauged, and the quantity of water which they discharge per day determined; the same should also be done for all the rivulets or small streams that cross the line of the canal throughout its course; and these experiments should be made not only where the streams cross the line, or levels, but at a considerable distance above and also below those points, the particulars of which experiments should be regularly and formally entered in a book, with all the attendant circumstances, and signed by the parties present at the making of them; as the same may prove of the most important use in future, either for detecting any secret leaks in the canal, or feeders by which any of these streams may be increased; or, in case of future claims being made for the water, or the diminution thereof by mill-owners or others, the company may be prepared, either to make a just retribution, or to resist ill-founded or ignorant claims with effect. For calculating the quantity of water discharged through gauges or apertures of different kinds and dimensions, theorems should be used which make the necessary allowance (deduced from experiment) for the form of the channels or apertures; such will be found in Dr. Young's abstract of M. Eytelwein's learned German work on Hydraulics, printed in the Journals of the Royal Institution, as also in Nicholson's *Journal*, 8vo. iii. 25. The survey of the summit of which we were speaking, ought to be accompanied by a plan, on which should be laid down the exact course of every valley and range of hill above the level of the proposed summit, with every particular of the nature of the soil in each; that in case reservoirs therein should be found necessary to collect rain or spring water, the necessary extent and probable supply of such can readily be determined at a subsequent period. From one end of the proposed summit-level it will be right now to proceed with the survey, tracing the level accurately and marking the same by pegs or stakes, that will last for some time, and be known by the surveyor, who is to follow and make a plan of the line; the levels being frequently transferred to what are called bench-marks, upon the trunk of a tree, a large post, or a building, the same being noted so particularly in the field or survey-book, that they may be readily found for years afterwards. We suppose the engineers, by this time, to have settled the rise that each lock should have, according to the dimensions adopted for the canal, the probable supply of water on the summit, and other circumstances; the summit-level will be traced as above, till the proper place occurs for making a fall of two or more locks, at about 100 yards or a little more from each other; and the places of these falls being marked, the level is again to be pursued and traced from the bottom of them, and marked out as before, till the opportunity occurs for another pair or more of locks, or till some obstacle, as a gentleman's park, houses, gardens, orchards, mills, roads, &c. present themselves at a distance; when it will be proper, after referring the level arrived at, to a proper and permanent mark, to proceed

forward, and to examine and well consider the different ways and levels, if more than one of such present themselves, by which the obstacle can be passed. From the most confined part of the course for the canal, owing to the obstacle, it will be right to level back, till the former work is met, and, in many instances, considerably overlapped, in order to determine the most eligible mode of bringing the two levels together, upon the principles before stated, if they can be applied, either by adding another lock, or taking one from any of the sets of them which had been before marked out, as occasion may require, and marking out the new levels thereby occasioned: the line between the summit and the first obstacle, or confined part of the course, being thus adjusted, a new point of departure is to be taken from such obstacle, and the level pursued as before, till the fall for a pair or more of locks can be gained, at the proper distance from each other. It is probable, that but few sets of locks can thus be determined upon before some new, and perhaps more formidable obstacle will present itself, which it will be necessary to break off for, and proceed forwards to consider, and to obviate as before; or the new difficulty may consist of some considerable lateral valley coming into the one which we are supposed to be pursuing, which may occasion an insurmountable or unadvisable length of embankment and aqueducts necessary, in order to pass it; or some gentleman's seat, mill, or town, may be found so completely occupying that side of the valley down which the line was proceeding; that the engineer may find it necessary to go back and revise a great deal of what he had done, perhaps quite up to the summit, and perhaps to take a new course down the other, or opposite side of the valley, or at least to determine where, with the least expence of embankment and aqueducts, the valley can be crossed to gain the opposite side. The places of the different sets of locks, or of single ones, if they cannot be avoided, and the line between each being adjusted anew, we will suppose the work again to proceed, till some new obstacle presents itself; this may be either a total change in the course of the valley that the line was pursuing, so as to render it necessary to begin to mount some other valley towards a new summit; or some gentleman's park, who is adverse to the measure, may so completely occupy the valley, down which the engineer is intent still upon pursuing his course, that it may be necessary to search out for the most eligible place for tunnelling through the hill into some adjacent valley, which is about to fall into the main valley. An instance of this latter kind occurred at King's Langley upon the *Grand Junction* canal, where the first Act provided for a tunnel of near half a mile in length, in order to avoid Cassiobury park: but the same has since been altered, and the course of the canal continued through this and some other parks, contributing not less to them in point of ornament than to the public in utility. It may happen, in case of a change of the direction of the valley, rendering it necessary to leave it, that some other valley may be at no great distance, into which the canal must be conveyed by a tunnel; and in order to render this practicable, it may be necessary to go back, and conduct a good deal of the line that had been done upon a new and much higher level, by omitting some of the locks, in order that the level may be conducted through, and supply the proposed tunnel: in accomplishing this, the former obstacles may recur again, or new and more formidable ones may be presented. In this way, the patience, perseverance, and abilities of the engineer must be exercised, until a practicable line of some length is obtained, and staked out; when the assistant land surveyor must follow, and make a correct and particular plan of the line of the

several proposed locks, embankments, tunnels, &c. upon the same, and of the several fields or pieces of land through which it passes, or that come within 100 or 150 yards of it in any part: it will likewise be the business of the surveyor to ascertain, with the utmost care, the boundary of every parish and township, what county each is in, the proper names of the owners and occupiers of every piece of land in each, however small, upon or within that distance of the line, with reference to the same upon his plan; and to describe correctly all public and private roads and paths that cross or intersect the line, and to and from what places they lead; the course of all brooks or streams of water, and particularly such as lead to, and contribute to the supply of any mill: the situation of the houses and towns upon the line, or within some miles of it, should also be determined; the nearer they are the greater accuracy will be necessary. We will now suppose the engineer proceeding with the line, from the end of a tunnel into a new valley, the course of which downwards is in the proper direction; the same process is to be repeated as was pursued in descending from the first summit, until this new valley changes its direction, or until some great town or work has been reached, and it becomes necessary to change the course of the canal, and begin to ascend some new valley or plain towards a new summit, or towards some mine or work, at which the canal is to terminate: to the new summit it will be necessary to proceed, and after settling the height of the summit level, and taking all the preparatory steps for ascertaining the supply of water, and other circumstances of this summit, as described respecting the first, the levels will be traced from this summit downwards, working backwards or up again, as often as obstacles may render it necessary, until the former work in the valley is met, and a proper junction of them contrived: the whole of this part being adjusted, the surveyor may proceed as before, with his plan and particulars: while we suppose the engineer returned to the first summit, and from which he will conduct his line, and avoid the obstacles thereon, in the best way that his ingenuity can suggest, until he arrives at the navigation or sea-port, at which his canal is to terminate, and where basins or docks, more or less capacious, according to the expected trade, and wharfs, cranes, and other conveniences, may want planning, for the accommodation of the traders and the public: all which the surveyor will proceed to survey and plan, as before mentioned. It may be necessary to remark, that every town, mine, or work, which happens to lie higher than the line, and to which a collateral cut is to be carried, must be considered as a separate summit, and provision for supplying the lockage thereof must be made, and such of the examination before described gone into, as may appear necessary; such towns, &c. as lie below the line, and are to have cuts or branches to them, will require water to be let down out of the line to supply their lockage; on which accounts, it is highly desirable, whenever the same is practicable, to conduct the line upon such a level, that the collateral cuts may be upon the same level, by which the trade thereon is much facilitated, and less water required.

A complete plan of the line, and all the projected collateral cuts, feeders, reservoirs, &c. being finished, the engineer will enter on a most careful revival of the whole scheme, with this plan in his hand; on which all the places where culverts or drains will be required, are to be marked, as also the proper places for the bridges, and the necessary alterations of the roads and paths, which will be cut off by the canal, so that the public may not be inconvenienced and turned long distances round about, and still, that as few

bridges as possible, and those in the least expensive places, may be erected. In some instances new channels will require to be cut for brooks and water-courses, to a considerable extent, in order to save culverts, or bring them to the most desirable spots. For proper security against accidental errors, the whole of the levelling should now be gone over again, and the several bench-marks compared, and renewed with the utmost care by the engineer's assistants, while he is proceeding with the necessary inquiries and calculations, for an estimate of the whole expence of the undertaking.

In a great number of instances it will be found, that the supplying of a canal with water, occasions no inconsiderable share of the whole expence, either in the first cost of mills or streams of water, in land for, and labour in, constructing reservoirs, engines to pump up water, &c.; or annually ever afterwards, in the fuel for, and repairing of, engines, hire of water from mills in dry seasons, &c.; this subject should, therefore, employ the most sedulous attention of the engineer, both to make the most economical use of what streams he finds, to procure other supplies of water at the least expence, but above all, to secure an abundant sufficiency. The dimensions and height of the locks, and breadth of the canal being settled, an accurate calculation made of the quantity of water required to fill a lock; and, with the largest probable number of boats that will pass in a day, the quantity required daily in every part of the canal; this, with a due allowance for the evaporation, from the surface of the whole canal and its reservoirs, and for the soakage that will take place into the banks, however well they are constructed; will show the number of locks full of water that will be required, from all the different sources. We have spoken of the steps proper to be taken for ascertaining the whole supply that can be had above the summit's level; and it will often be necessary to make a similar investigation, on points below that level, and to construct reservoirs in such situations, to supply the necessary lockage, for local trade upon the line, near any great town or works, which does not extend to the summit, as also to supply the evaporation and soakage of long lengths, in situations where feeders or springs cannot be taken in by the way; another use of reservoirs in less elevated situations may be, to compensate mills that are lower down the streams for the water that is taken for the use of the canal from the higher branches, or near the sources of such streams. For Mr. *William Jessop's* observations on this subject we refer to *William Pitt's General View of the Agriculture of Staffordshire*, and to the *Repertory*, vol. iii. p. 243.

There appears no reason, under the present state of things, why the owner of a mill or stream of water should not be compellable to part with the same, for the purposes of a public canal, any more than another man to part with his field, except the accommodation which the public receive from such mill; and where the same, or a superior accommodation, can be ensured to the public, surely this species of property ought to be put upon the same footing with land in general. See Dr. *James Anderson's* Essays, vol. iii. p. 68 to 76.

It ought to be considered, that the present state of our canals and inland navigations, and especially the extension of them, which we are now supposing, remove one of the principal objections to steam engines, by enabling new mines of coals to be daily opened, and the products thereof, as well as of the old mines, to be regularly and cheaply conveyed to every situation where engines can be wanted. We would not, however, be supposed to recommend the annihilation of water-mills; on the contrary, it hath long appeared

to us, that their number and their power might, in some, and perhaps in most instances, be greatly increased, and yet all the purposes of canals be fully answered, and those most capital improvements of irrigation and drainage at the same time extended, to very large tracts of land; for this purpose it would be necessary, that an entire valley of considerable extent, that has a good stream of water through it, as the *Colne*, or the *Lea* near London, for instance, should be put under a system of improvement. A thoroughly competent engineer being employed upon such a work, would be able to conduct a canal rather of large dimensions perhaps, along one side of the valley downwards, until three or four locks, or a fall of 20 to 30 feet was obtained; and, the water in the pound below such set of locks to be a small distance below the level of the surface of the ground, in the lowest part of the valley at that place, as this would enable the whole stream of the river to be taken into the next length of level, as often as occasion should require it: this new level would be traced, until, by the fall of the valley, it has reached the sides of the hills, and proceeded with until another set of locks, three or four in number, can be obtained, and a descent made again to the level of the lowest point of the valley: this process to be continued through the whole length of the valley, under improvement. The next consideration would be, a deep and effectual drain, to be carried up through the whole length of the valley, pursuing the lowest ground, and the middle of the valley nearly, in such parts where the hills on each side rise equally abrupt; but where, as often happens, the descent to the valley on one side is very sudden and steep, and on the other side long and gradual; in all such cases the drain should be conducted nearer to the abrupt than to the easy side of the vale, because here the peat or alluvial matters, with which such valleys are choked up, will be found the deepest, and the springs in the gravel underneath such peat, the most copious and the most confined; the new drain ought, in general, to reach the gravel under the peat or filth; and where this shall be found impracticable, large auger holes ought to be bored at short distances from each other, quite through the consolidated peat and filth, to the gravel, to set the confined springs therein at liberty. These principles of draining a boggy valley we have seen successfully practised in the village of Crawley, below Woodburn in Bedfordshire, by an agent of the late worthy duke of Bedford.

If the fall in the new drain should be found very considerable, the same must be reduced, by placing weirs or well-falls at proper places, to let the stream down in a harmless manner, which would otherwise displace the gravel and sand under the peat, and the same would cave in, so as to fill up and destroy the drain: another excellent use of these well-falls or weirs will be, to furnish so many points, where the whole stream, including the springs, can be taken out to supply the upper end of the levels of the canal before mentioned, or for the purposes of irrigation; as was intended and provided for, in the Crawley vale that we have been speaking of. To all the existing mills, which are not too ruinous or badly constructed to be worth improving, the channels to the water-wheels should be deepened up from the main drain, or, perhaps, in most instances, new and more direct ones cut. It will now be practicable for the engineer, in most if not in all cases, to construct an *over-shot* water-wheel upon the same axis that before carried an *under-shot* one, turning the same way and with the same velocity as before, so that the internal machinery of the mill will need no alteration; and the requisite quantity of water for working these new wheels, which in most cases will be inconsiderable, may be conveyed from the canal on the side of the adjoining hill, in

aqueducts or elevated troughs of no very expensive construction, perhaps of cast iron, or in pipes, which may be conducted under ground, and rise up to small reservoirs or pen-troughs above the wheels. As many of the mills will be found situated on the opposite side of the vale from the canal, it may be proper and advisable in most cases, to construct a cut or water-carriage of sufficient dimensions, and with a very slight fall, along that other side of the vale, beginning frequently at the weirs or well falls in the main drain or new brook, and pursuing the level nearly, as far as is found requisite; which cuts will much extend the benefits of irrigation, and give opportunities, perhaps, of constructing new mills, with over-shot wheels of large diameters and proportionate power, to be supplied therefrom. In like manner, several new and powerful over-shot mills may perhaps be constructed near to the several sets of locks upon the canal, without endangering the sufficiency of water for the lockage: this practice of uniting navigation and mill improvements at the same time, we were much pleased to see enforced by Mr. Thomas Telford, in his Report of 1801, printed by order of parliament, upon the intended *Inverness and Fort William* canal, p. 46: and the same has been suggested as an appendage to the Woolverton embankment on the *Grand Junction* canal; see the *Agricultural Magazine*, vol. viii. p. 24. New and improved mills may often be constructed where the point of a hill at a great and sudden bend of the river can be tunnelled through, from the river on the upper side, as appears to have been done at Shrewsbury on the *Severn*, and at Stanley on the *Tay* rivers.

Where the new drain or brook course connects with the levels of the canal in the improvement of a valley, as above proposed, if floods are to be apprehended, or the water is ever found very thick and muddy, weirs or over-falls sufficiently large to let the flood escape down the drain must be constructed, and stop-planks provided to be put down across the canal occasionally, or a lock capable of a very small fall constructed, to be occasionally used, to prevent very muddy waters from entering the canal to silt it up. It will frequently happen, that brooks which are making their way laterally into a valley under improvement, may by an alteration of their channel for some distance up the collateral valley, be brought into the canal in places where a considerable elevation on the side of the hill has been attained, in such cases a circular weir or well-fall should be constructed in the centre of an enlarged part of the brook, before it arrives at the canal, as has been done by Mr. James Brindley, at the mouth of Medlock brook at Manchester, on *Bridgewater's* canal; a provision for stop-planks, at the junction with the canal, will also be proper, to be enabled to turn occasional muddy water down the well fall instead of into the canal. In order to preserve a sufficient elevation in the water-course, for supplying of mills, or for irrigation, after the canal has descended a set of locks, and is consequently too low for this purpose, a cut or water-carriage may be taken out of the summit's level, and carried on along the side of the hill with a proper fall, as far as may be necessary. This system of improvement in a valley, is capable of being combined with an extensive application of reservoirs, for equalizing the head and collateral streams which supply such valley, as recommended by Mr. W. Jessop.

In cases where the land or park owners cannot be brought to concur in a general system of improving a valley, it would often be worth while for a canal company to obtain power from the legislature to purchase all or most of the mills in a valley, through which their canal is to pass, paying, in the first instance, the utmost value for them; and being also bound to erect the same number of mills, of equal or su-

perior power, and adapted to the same purposes, to be supplied from higher levels in the manner we have been describing; such new mills to be offered at a fair price, to be settled by indifferent persons, to the owners of the adjoining old mills, before the same are disturbed in the use of the old mills; and in case of their refusal to purchase, the same to be next offered to the persons who may be tenants to the old mills (in order that they may not be thrown out of employ); and then to any other persons inclined to become purchasers, on such terms as they and the canal company could agree upon.

Sometimes it may be practicable to make a bargain for taking weekly into the canal, a stream of water which supplies a mill, only from Saturday night to Sunday night, paying a fixed rent for the same, to be secured by the act; an instance of which occurs upon the *Montgomery* canal.

The subject of supplying water for a canal having been amply illustrated, we shall now return to the revival of the survey, and making an estimate of the expence of the undertaking, on which we supposed our engineer to be employed. In revising the survey of the line, it may be proper for the engineer to cause holes to be dug at certain distances, as deep as the canal will require to be cut, or deeper, to inform himself more perfectly of the soil to be cut in, and the expence attending the same, noting particularly the height to which springs may rise in the several holes. And here it may be proper to notice a very common error, into which the persons entrusted to execute canals have fallen, in such parts where springs appeared beneath the surface in the cutting, by concluding that the canal would make water, as they term it, in such parts, and that puddling was unnecessary; but where too often it has afterwards happened, that such springs, from having a variety of other vents or outlets, at or very near to the same level, and were, therefore, incapable of being dammed or raised much higher than they then appeared; when the canal has come to be filled with water to a higher level, the course of such springs has been reversed, and the porous strata through which they passed have served to absorb and discharge the water at other places, to a very fatal extent. Land-springs, or such as run only in winter, have generally the same effect, and in summer as copiously take in water, when their own source fails, as they before discharged it. The difficulty of puddling or lining out springs, on account of the powerful effort they make to force their way through the lining, as long as the canal remains empty at first of water, will induce a careful engineer, to endeavour to avoid, if practicable, all springs that will not at all times rise to a higher level than the water is to stand in his canal. It will be part of the business of this revival of the line, to examine what can be done to straighten the canal, we mean as to sudden bends, by small lengths of deep-cutting, and others of embankment, to correct the plan accordingly, and to estimate the extra expence of all such works. The lengths and solid contents of the several embankments, and the distance from which the stuff or soil must be fetched for the same; the lengths and dimensions of all the deep-cuttings, and the distance to which the stuff must be removed; the lengths of the tunnels, and number and depths of the several shafts or tunnel-pits that will be necessary; the lengths of headings or soughs that will be wanted to drain the tunnelling works; these, and all the great variety of other works, some of which we have already mentioned, and others that we shall have occasion to mention in the sequel, being particularly stated, and prices fixed to each species of work and kind of material; and these prices ought by no means to be below the current prices of the best articles of the kind at the time, but due allowance

should also be made for the advance of prices, which will take place during the execution of the work. The total probable expence, with a due allowance for contingencies, being thus obtained, the engineer will prepare his general report and estimate, to be laid, with the plan, before a meeting of the adventurers or proposed proprietors.

The next step in the progress of this business, after the appointment of a solicitor of competent legal knowledge, is an application to parliament for an act, empowering the parties concerned to complete their undertaking.

From the earliest times, the parliaments of this country have found it necessary to adopt certain standing-orders, or general rules, to be observed by the parties who applied for any act of a local or private nature; and these seem to have guided the conduct of canal projectors, till the number and variety of such applications shewed the necessity of adopting, on the 7th of May 1794, thirteen special resolutions, as standing orders, relating to the introduction and passing through the house of commons, of any acts for navigable canals, or aqueducts, or for the navigation of rivers; to these another was added on the 16th June 1795, respecting intended reservoirs and feeders to a canal or navigation; and another on the 25th June 1799, applying the former orders to rail-ways or drain-roads, as far as the same are applicable. The house of lords have a nearly similar set of standing orders, and one requiring a sufficient number of copies of an engraved map of the intended canal, &c. to be delivered for the use of each member of that house.

The number of clauses, relating to the construction and management of a canal, are necessarily very numerous, and it were much to be wished, that the proposition of Mr. *John Church*, in several periodical works, for a general canal act, to contain all their general clauses and provisions, in the same way as the general highway and turnpike acts, and the general inclosure act, could be accomplished; it would much shorten and simplify the business of canal acts and management. Another general measure, relating to canals, we beg here to mention, although the application to parliament in the session just now passed (1805) did not prove successful, we mean the proposal for a *general canal company*, for raising a large fund, to be invested in shares of canals not yet raised, and for lending money at interest, to such canal companies as may require it, to enable them to complete and render their several concerns more generally beneficial.

Mr. *William Chapman*, when speaking of the navigations of America, says, (Observations, p. 64.) "It will be advisable in a rising country, to lay out the lines of canals approximately on its first settlement; reserving a proper width for them, in the original grant of the lands, with power to exchange the land of that line, for any other found more convenient, on a full investigation; and thus avoid all the difficulties attendant on those measures in England." Does not the period of the inclosure of a parish here furnish the same opportunity of considering the eligible line for a canal; and of so contriving the allotments that very few, or perhaps only one person's land may require to be cut into, upon the adoption of such measures, and that without cutting up or deranging the system of his or their estate? We were happy to see this idea acted upon, as far as irrigation is concerned, in the parish of Maulden, in Houghton-Regis near Dunstable, (into which a cut from the *Grand Junction* canal was proposed to be brought,) and in some other parishes in Bedfordshire, about the year 1797, by the late duke of Bedford's agent.

One of the first objects of a canal act is, to incorporate and make a body politic of the proprietors, by a certain name and style, by which they shall have perpetual succession

and a common seal, and by which they may sue and be sued, and have power to purchase lands, to them, their *successors*, and assigns, for the use of the undertaking, without incurring the penalties and forfeitures of the statutes of mortmain; and to enable the company to sell any lands so purchased. The selection of the name for a canal, is of more consequence than would at first sight appear. Since canal and rail-way companies have multiplied to very much, it is necessary on all occasions to adhere to and use their incorporate or *parliamentary names*, a circumstance which has not been attended to sufficiently, but such a variety of names have been used, in the printed accounts of events upon or relating to our canals, that it is often impossible to avoid mistakes.

It has been usual to enable the company to raise a fixed sum of money, equal to or exceeding the total estimate of expences, by subscription or shares; and, in case of this proving inadequate, to borrow a further fixed sum upon interest, or on mortgage of the tolls. The many and expensive acts of parliament that canal companies have been obliged to obtain in the course of their work, for powers to raise further sums, and even for regulating and enforcing the mode of raising the sums first authorized, shew the necessity of the engineer and solicitor paying great attention to this point, and to be careful to apply for powers sufficiently ample.

The usual amount of shares in canal companies is 100l. but instances of 50l. shares, and others of less or greater value, occur in several of these establishments. These circumstances ought always to be particularly attended to in comparing or quoting the prices of shares in different concerns; and we strongly recommend all future shares to be 100l. ones, especially as the legislature will permit of half shares, or even lower divisions, down to the eighth of a share, as appears in the *Grand Junction* act, 43 Geo. III.

To prevent the interest of any individuals from preponderating, and to increase the number of persons having an interest in the success of the undertaking, it has been usual to limit the number of shares which any individual can hold, under forfeiture of all above that number, except they came to him or her by will, marriage, or other legal process.

The election of a committee of management, and all questions agitated in the company are decided by votes, not personally, but according to the number of shares held by each person, to a limited extent, and usually two half shares carry one vote. The usual limitation to prevent any individuals from possessing too great power in the company is, that no more than 15, or sometimes 20 votes shall be given by one person; while in the *Newcastle-under-Lime* only 6 votes are allowed; and in the *Croydon*, *Peak forest*, and *Thames and Medway*, no more than 5 votes can be given by any one proprietor.

General meetings of all the proprietors are provided for, on any important occasion, as well as annually to elect the committee and officers.

Provision should be made for progressive calls on the proprietors, by the committee, for their several subscriptions; these should be on as long notice as is eligible; but they must be prompt and strictly enforced, or the progress of the works will suffer.

The enactments relating to purchasing of lands, and ascertaining the value thereof, where the parties and the company's servants do not agree, by means of the commissioners, will be necessary, who generally consist of all the considerable land-owners of the county, or of a jury to be impanelled for such purpose, these ought to be very clear and explicit: so should the regulations and forms for selling and transferring shares in the concern.

The most ample powers should be given to enter upon,

and dig, and construct, both the permanent and all temporary works which may be necessary; with provisions, in case of refusal, to accept the compensation offered for damage; that the commissioners or a jury shall settle the same without delay or further appeal, except, in some instances, to the next quarter-session of the county.

A clause is generally inserted, confining the company to the line that is laid down in the plans that have been deposited with the clerk of the peace and with the house of commons, or within certain limits on each side thereof; the usual deviation distance allowed is 100 yards; however, many instances have occurred, which shew how very important it is to the proprietors, that the line of the canal, and every probable cause for the necessity of deviation, should have been thoroughly examined and weighed by the engineer, and the line ultimately adjusted, before the plans are completed and delivered.

The prudent precaution of the legislature, has always limited the width of land which canal proprietors have been empowered to purchase for their canal, in ordinary cases, without the free consent of the owners; this has been 26 and 30 yards, in the greater number of instances, but in others the space allowed for the canal towing-path and fences has been less or greater, according to circumstances.

Where wharfs, docks, or basons, or places for barges to turn and pass each other, or where deep-cutting or embankments are required, it has been usual to allow 100 yards in width to be purchased; but from this allowance there have been occasional deviations.

Except in some rare and peculiar instances, like the *London Docks* in Wapping, the parliament will not give to any company the power of purchasing houses or other buildings, gardens, orchards, yards, parks, paddocks, or planted walks or avenues leading to any house, except the previous consent of the owners thereof be obtained; and where this has been got, it is the safest way to insert a list of all such owners, with a description of the property they have agreed to give up, as a schedule to the bill: and the same of all material contracts for mills, streams of water, or springs, which the company may have made. Houses built, or orchards, &c. made as obstructions, since the survey was made, and notices given, will not meet with the same protection; and a clause ought to be inserted to put them upon the same footing with lands in general.

Powers should be given for erecting public wharfs, and for demanding and enforcing certain equitable rates of wharfage for goods, according to the length of their continuance on the company's premises.

The toll, or rates of tonnage, which the traders are to pay to the company per ton per mile for the liberty of navigating upon the canal, or its various branches, rail-ways, or inclined planes, require the most deliberate consideration, that every species of trade may pay its proportion, and none be discouraged or lessened by the expences of conveyance.

In some cases provision has been made, that when the net profits of the concern exceed a certain rate per cent. the tonnage or tolls should be reduced.

There have been exemptions from tolls, on several canals, in favour of officers and soldiers on their march, with their horses, arms, and baggage. Timber for the use of his majesty's navy, and government stores of all kinds sometimes pass toll free; so do gravel or other materials for the making or repair of roads in most instances. In some cases, canals have been projected principally with a view to tonnage on lime, and other manures and agricultural objects and produce; but with this exception, it has been usual to allow lime and all manures to pass, either on very low tonnage, or absolutely

toll free, on the levels, and through the locks also on some, particularly when the water actually runs over, or is within a quarter or half an inch of the top of the lock-weirs; in some instances, several hours notice is required, of boats with manure or road-materials intending to pass any locks toll-free. In some instances, where a canal is to run parallel to a turnpike road, and is expected to lessen the tolls thereof, by the diminution of heavy waggons and carts, it has been usual to compensate or indemnify the creditors on such roads; and it seems equally just, where a turnpike road crosses a canal, and is likely to have its tolls both ways increased, that they should not be entitled to receive materials by the canal tonnage free.

Mile-stones are directed to be fixed on banks of most canals, for regulating the distances and tonnage; in several instances, these are directed to be placed every half mile, and in others one is to be placed at the end of every quarter of a mile.

We should far exceed our due limits, if we were minutely to recount the various expedients that have been adopted for conciliating the owners of lands, parks, mills, &c. who may more or less be affected by different canals. These must depend on a variety of local and incidental circumstances, for the adjustment of which no general rules can be prescribed. But in all cases of this kind the canal companies have usually proposed, and the legislature has sanctioned, an adequate compensation. Proprietors of land and their tenants are sometimes allowed the use of the towing-path, as a drift and bridle-way between their different lands, or to some public road; the owners of the adjoining lands are often allowed to make, not only docks and basons communicating with the canal, but collateral cuts of considerable extent, to their mines and other works; but previous notice of all such intentions ought to be given to the company, that their engineer may examine the ground, and direct the necessary puddling and other precautions, to secure the line of canal from losing water to a prejudicial extent thereby.

The company are often empowered, and sometimes required, to make collateral cuts, or rail-way branches to particular towns, mines, or works; and a very proper precaution seems to have been adopted in the *Somerset Coal* canal act, that the parties to be benefited by such branches should first give the company security to make up the tolls thereof, by an annual payment, in case of their falling short of a reasonable interest on the money expended upon such branches.

In some instances it may be necessary, particularly on rail-ways, to permit individuals to construct and manage such part of the works as pass through their own park or ground, but subject to the general system of management laid down in the act; as is done by the *duke of Beaufort* on the *Swansea* canal, and by *Mr Charles Morgan* on the *Sirhowy* tram-road; also to construct particular parts, on being paid for the same, as was done by the *Dee* river company, at the crossing of the *Ellesmere* canal.

Clauses are generally inserted, requiring the canal company to remove and clamp the top soil, or vegetable mould, to the depth of nine inches, from the whole width of the intended works; which, after the same has been completed, and all the banks and excavations properly sloped down, is to be returned and spread upon them, so as to render all the land, not actually occupied by the canal and works, capable of cultivation; but a small part of this top soil is wanted in general upon the banks, and it might, more profitably for all parties, be filled by the company's men into the carts of the neighbouring farmers, to be spread upon the poorer parts of their lands.

Watering places for cattle are generally directed to be made,

especially where the fields may have been deprived of their old ones by the cutting of their canal. In counties where irrigation is much practised, as in Wiltshire and some others, it has been common to appoint skilful and reputable persons to guard the interests of the irrigators, on the cutting of canals.

On the duke of *Bridgewater's* canal, irrigation trunks were laid below the bottom of the canal, so that, by means of a harrow, or rather a large hoe, drawn along, the mud of the canal was drawn to the valve or orifice of the trunk when open, and the mud was thus conveyed to the meadows below. A successful experiment was here also made, of bringing up barges laden with sea fish, or mud taken up at low water, in the Mersey, and this was gradually poured or thrown out into the canal, over the irrigation trunks while running, by which means this valuable manure was at once conveyed to and effectually spread on the meadows below. We have been greatly surprised to find irrigation so little practised upon the lands below canals, which so perfectly admit of that improvement; were this subject properly attended to, in situations where water is plenty, we doubt not but some proprietors or lessees of land would be found, who would readily contract with the engineer, on the part of the company, before the canal is completed, to pay an annual rent for certain quantities of water, to be let out by the company's agents, at stated times, through a trunk, which might be laid beneath, or level with the bottom of the canal for such purpose, at a very easy expence, before the water was let into the canal; and even after canals are completed, there are situations where the interest of all parties might be served, by laying trunks for irrigation; and perhaps farmers ought not, except in some few instances, to be debarred from constructing or using proper weirs at the same immovable height, or a little higher than those at the lock-gates, to take off the surplus water for irrigating during the winter season.

Sometimes it will happen that a canal can be conducted on a proper level to suit the adits to mines, as at *Worsley* on *Bridgewater's* canal, and some others; or perhaps the tunnel through a hill may be applicable to mining purposes also, as at *Morwelham* down, on the *Tarvisstock*, near *Ripley* on the *Cromford*, the *Harcastle* tunnel on the *Trent and Mersey*, and others.

Coal-mines may be allowed to have the necessary passages for their works under a canal, but should be restricted in the number, width, and height of these, as on the old *Birmingham* canal; or if the veins are near the surface, the ground may be so entirely broke in, that the canal would be destroyed, as has actually happened on some of the branches of the above-mentioned canal, near to *Wednesbury*.

Respecting mills, it may be necessary sometimes, where the canal is to be conducted near to established mills, that they should be secured against other mills in the same line of business being erected on the canal at that place, as in the *Saukey* canal act. Sometimes gauge-weirs, or self-regulating sluices, may be necessary to be maintained, to supply mills or other canals with a regular and constant quantity of water; instances of which occur on the *Rochdale* canal, and at the *Amsworth* reservoir, on the *Nottingham* canal; the theory of the regulating sluice, in the latter place, will be found in the *Gentleman's Diary*, 1799, p. 43. by that eminent mathematician and coal-worker, *Mr. Thomas Walker*, of *Bilborough*; and if theorems for the widths and heights of sluices to dis-

perhaps consult the *Croydon* canal act, for the clauses relating to the *Wandle* river.

Where a connection is to be made with any other canal lying upon a higher level, or even the same level, where leakage or waste of water is to be apprehended, that would be prejudicial to either of the canals, it is usual to provide, that a stop-gate shall be erected at or near the junction, which one or both of the canal companies are empowered to shut and lock up whenever there is such a lowering or draught of water upon one of the canals, as would endanger the supply or lower the head of the other; clauses for these purposes will be found in the *Deane and Darby*, *Dudley*, *Stratford*, *Warwick and Birmingham*, *Wychly and Effington*, and other acts. And when any canal joins another, coming down from a hilly country, it is usual to require tall-gates to be erected, with capacious weirs for preventing of floods from the upper canals making their way into the lower one, as in the *Abberdon* canal. It will very often happen, that tolls or dues will be to be paid by barges for entering any of the existing navigations from the new canal, or vice versa. And where the new scheme can be so poised to interfere materially with the trade on any former one, it has not been unusual to guarantee that their net profits or tonnage shall not be less, after the completion of the new canal, than before; or sometimes annual payments are agreed to be made as compensations for the expected losses to older navigations; and in some instances, where the rivalship is expected to be very formidable, as on the *Douglas River* by the *Ludd and Liverpool*, and the *Dorset River* by the *Dorset* canal, provision has been made, that the old concern shall be purchased by the new proprietors at a fixed sum; the settlement of the various compensations that may be necessary on a canal are often such as to require the exertion of the utmost abilities of the engineer, with the most able assistance, as the very long and complicated clauses in many acts will shew.

On applying to parliament for any considerable extension of a canal, or to raise more money, there are instances, and perhaps very proper ones, of enacting that the shares of certain discontented proprietors should be purchased out of the new funds, as on the *Dudley*, the *Kennet and Avon*, and others.

So attentive has the legislature been, even to the comfort of proprietors or inhabitants near intended canals, that it has been enacted, as on the *Barnsley* canal, that where steam engines were to be erected in certain places, for the use of the canal, their fire-places should be so constructed as to consume the smoke.

Ample provisions should be made, for powers to make bye laws for regulating the trade upon the canal, for the form and dimensions of the barges or boats to be used thereon, and for passing the locks, inclined planes, &c. that may be thereon. It is necessary to declare, that the canal is not to be subject to the interference of the general commission of sewers; manorial rights, and fisheries in old streams, or waters ought to be reserved; and it would be well for the encouragement of these great national improvements, if the legislature would permit a clause to stand, as in the older acts for *Bridgewater's* and other canals, that the proceedings and writings of the company should be valid without stamps.

It has been usual to enact penalties for a variety of offences likely to be committed upon the canal; and for malicious damaging or destroying of the works to declare the offenders

with advantage. Those who may wish to see how the ingenuity of mill-owners can be exercised to secure themselves against possible injury, or even to thwart a canal scheme, may

into consideration at the period of framing the act of parliament, some of which we shall avoid repetition by mentioning, when stating what occurs to us on the practice of executing

and managing canals, to which we are now anxious to proceed.

The act of parliament for a canal being passed, and therein the time and place for the first meeting of the subscribers or proprietors thereof being fixed; one of the first businesses of such meeting will be the election of a *general committee of management*, consisting of the most independent, respectable, and generally informed persons among the proprietors. The committee of management will then proceed to elect a chairman and subordinate officers; to fix upon their place of meeting, and to arrange the order of their business.

It will not often happen that the engineer can be spared from the projection and superintendence of other great concerns, to attend to the cutting of the canal and erection of the several works, without the assistance of a *resident engineer*, or more than one, if the line be of considerable length, and distant parts of it are intended to be proceeded with at the same time; and the committee will do well to leave it to their engineer to recommend all such assistant or resident engineers from among those who have been brought up or employed under him, or are well known and approved by him, for their mathematical knowledge and practical skill, experience and attention in the several kinds of works that are to be executed. The attention of the committee should be directed to fixing upon some *land surveyor and valuer* of respectability and great practical knowledge, who has been used to and acquired address in the negotiation and settlement of purchases and exchanges of property of different kinds; and if he has before been employed upon canals he will be so much the more fit. In this stage of the business it may be well also for the committee to consider whether any *local committees*, or a *select committee*, may be necessary, to pay the more minute attention to, and to bring before them, the concerns of particular districts of the canal, and to serve other purposes.

The body of the proprietors, assembled in a general meeting for the purpose of completing the organization of the affairs of the company, will proceed to the choice of a certain number of auditors of their accounts, and to settle the salaries of all the persons that are employed.

Most canal acts direct, that two copies of the plan of the canal and book of reference, with any amendments or alterations that may have been made in parliament, are to be certified by the signature of the speaker of the house of commons; one of which is to be lodged with the clerk of the peace for the county, and the other with the clerk to the company, who are required to produce the same, and suffer copies or extracts therefrom to be at any time taken by any person, and to produce the original before the committee, or any jury who may be called on to decide any matter or dispute relating to the making or maintaining and using of the canal.

The engineer being now informed of the exact bounds within which the law has confined his operations, and of the several restrictions or alterations that may have been imposed or made since his former surveys, will, in all probability, find it necessary to look over the line and all the proposed works again, accompanied by the intended resident engineers; and, in such revival, it will be proper to divide the line of canal, and the several works thereof, into the necessary number of parts, and to give concise and definite names to each, that are to be used in future, in contracts and bills, &c. of which distinct parts or divisions a separate account of the expences should be strictly kept by the resident engineer, the *overseers*, or counters as they are generally called, (that the engineer is to recommend or employ upon the works) and by the office-clerks in a ledger, with proper

heads for each length of canal, set of locks, tunnel, embankment, deep-cutting, reservoir, aqueduct, or other great work, that may form a separate division: such particular and divided accounts of the works will prove of the most essential service to the committee, and to all others concerned, in informing and maturing their judgment on the actual or probable expence of every different kind of work; and will enable the committee to account to the proprietors how great, and sometimes unavoidable, as well as unexpected, expences may be incurred.

The committee should now well consider and inquire, whether any particular part of the line can be completed and opened with advantage, before the whole length can be got ready; and this being determined upon, the engineer should compare and consider, from the estimates and particulars that he possesses, the comparative length of time that every particular work upon the length intended to be first completed will require; and in this order, or with a proportionate exertion and number of men, should the several works be entered upon. Immediately after the plan has been settled, preparations should be made for providing all necessary utensils and implements.

The Act for a canal should give the company and their servants power to enter upon and occupy, for the temporary purposes of their works, heaps of soil, &c. any land except parks, orchards, and gardens, within the limited distance, on condition of their making a full and ample satisfaction, by annual rent, to the former occupier or lessee, and for all damage to the owner and occupier, so soon as the works are completed, and the heaps, &c. can be removed or levelled down, and covered with soil. The tunnels, deep-cuttings, embankments, or other great works, that are first to be begun, (and the levels, widths, &c. of which we suppose to be completely settled,) should be now marked upon the ground, with the necessary allowance of width for the slopes, and the spoil-banks, which the engineer may judge right to remain the permanent property of the company.

The land-surveyor should now proceed to treat, under the direction of the committee and the engineers, with the several parties who are entitled to the land that is wanted; for this purpose, it will be right for the surveyor to prepare correct and explicit plans and admeasurements of every piece of land, and, in many instances, to deliver copies of the same to the parties; to consider well the intrinsic value of the land to the owner, and of any extrinsic or artificial value which it possesses, with ample allowance for the injury that his remaining property will sustain by being detached, or by the fields being cut into inconvenient and awkward shapes, or on any other account.

It is generally provided, in canal acts, that where any person's estate is cut in two by the canal, and a part, consisting of less than a certain quantity, is severed from the rest, the company shall be compellable to purchase such detached part, if the party wishes it. And it ought to be provided, that the company are not to be obliged to make an occupation-bridge for less than a certain number of acres, unless the dwelling-house or farm-premises of the estate happen to stand upon such small detached part.

As soon as the surveyor has made his contracts or short agreements with the parties, containing a full description of the lands or other property to be purchased, the same will probably be put by the committee into the hands of the clerk to the company, with directions for him to enquire into the nature of the titles of the parties, and prepare conveyances accordingly, in the short and summary form that the Act ought to provide for such purpose: in like manner,

where the parties who own the estate could not be come at, or have not been brought to agree by the surveyor, he should furnish the committee with the particulars of such property, the price offered, and other particulars of the negotiation; in order that the clerk may be directed to prepare the necessary notices for a meeting of the commissioners described in the act, or a warrant to the sheriff of the county for empanelling a jury to hear the evidence, who are to be summoned on the part of the company, and those produced by the owner of the estate, and to view and examine the premises if necessary, and to give their verdict or assessment of the sum that is to be paid by the company, and accepted by the parties.

The ground for the necessary reservoirs, to supply the part of the line that is to be begun, ought to be among the first that is marked out, including space for the head or new embankment that is to be made, and should be treated for and purchased by the surveyor, and conveyed as above mentioned. The ground whereon the locks are to be built, or any wharf or walled basins are to be made, should also be carefully ascertained by the engineer, and purchased in an early stage of the business, in order that the summer seasons may be fully embraced, for the building of all the masonry and brick-work.

The modern acts for canals usually contain a clause, requiring all the top-soil to be removed. This, of course, will be attended to before any of the works are begun.

It has been found, from experience, that the banks of canals against which the water is to lie, ought, in general, to have their slopes so apportioned, that one foot in depth will give a horizontal base of one and a half foot; and to these or some proportions near them, rather above than below, as slopes of $1\frac{1}{2}$ to 1 are in general too small, will the widths at top and bottom, and the depth of the intended canal probably be fixed by the engineer: and it has been found convenient and proper to make up the banks of canals one foot higher than the water is intended to stand in them.

We are now to suppose the resident engineer to be proceeding with the setting out of the canal, being furnished with a map of the several fields through which it is to pass, the line that is provisionally settled for its course, but with liberty to deviate within certain limits therefrom, and with bench-marks which the engineer has left and described at certain distances, to regulate the top-water level, or height of the water in the intended canal; and, as above observed, one foot higher will be the level of the top-bank, or height of the banks.

It will be proper for this engineer, and we shall in future, for the sake of distinction, denominate the other the *principal engineer*, to trace the levels accurately of each pound or level reach of the canal, and to put in level-pegs or small stakes, at every two or three chains, more or less according as the ground is more or less undulating, as he proceeds; wherever the canal is conducted along the side of a hill, as will happen in a great portion of its length, the level-pegs are not to be placed exactly along the line that the principal engineer has marked out, but either above or below that line, as the slope of the hill may occasion, exactly at that point in every place, where the level of the top-bank (traced by means of a good spirit-level, with telescopic sights) cuts or intersects the surface of the hill. In some places it will be found that the principal engineer has drawn his line across the point of a hill, so as to occasion deeper cutting than usual, to avoid going round it; or, on the contrary, crossed a vale or low place, so as to require less cutting or perhaps none at all, to avoid taking a circuit

up that vale to follow the level of the ground; and if either of these deviations should be so considerable that the level-peg would fall more than two chains or thereabouts from the line, down or up the slope of the ground, the plan of having level-pegs upon the surface must be departed from, and holes should, in the first case, be dug at proper distances in the line, and pegs put into the same with their tops to the right height; or, in the second case, longer and flouter stakes should be used, particularly in the fences that are crossed by the line, or other places where they will not be liable to disturbance, and drove firm into the ground till their tops mark the right level. In tracing these levels, the engineer will refer to and compare his work with all the bench-marks before described, and at each end of a level or reach, will level up and down to the bench-marks of the reach above and below the one he has been working at, and compare the same with the fall that the locks at each place are intended to have. And we recommend particularly to the engineer to be very punctual in entering minutely in his field-book the particulars and situations of the several level-pegs, and to make one or more of the men who assist him in levelling, perfectly acquainted with the situations and distinguishing marks of them, and frequently to cause them to be looked over and renewed; or continual repetitions of considerable lengths of the work will be necessary, owing to the disturbance and loss of the pegs by the cultivation of the fields and treading of the cattle, or by the interference of idle and mischievous persons of the country. Too much caution cannot ultimately be taken, by frequent reference to the bench-marks, with due allowance for any accidental variation that may have been discovered among them, and repetitions of the levelling, to avoid those disgraceful blunders into which some less capable and less careful engineers have fallen.

We are now to consider, that the great *defideratum* in canal digging is, that the stuff that is dug from one part of the work, shall, with the least labour or distance of moving, exactly supply or form the banks that are to be raised in another; so that on the completion of the work, no spoil-banks or heaps of useless soil shall remain, or any ground be unnecessarily rendered useless by excavations or pits. Six different cases will be found frequently to occur in the cutting or forming of a canal. (*Plate I. Canal, figs. 1, 2, 3, 4, 5, and 6.*) A'A E L P P' being, in every case, the line or surface of the ground across the canal; A B C E, in the first five cases, the bank on which the towing-path is to be made, and therefore generally the widest; L I K P in *figs. 1, 2, and 5*, the off or smaller bank; C I is the top, F G the bottom, and C F and I G the sloping sides of the canal, in every case. The bench or berm, I K, in *figs. 3 and 6*, is provided to retain and prevent the loose earth that may moulder down from the upper bank P K from falling into the canal. Sometimes the interference of proprietors, or other causes, may occasion the towing path to occupy the bank, or place of the bench I K, instead of B C, which will cause a considerable difference in the calculation or measure of the stuff to be moved in *figs. 2, 3, and 5*, but the same do not properly form new cases. The first case occurs most frequently in cutting across or along level meadows, and we were not so well able, when treating of the first survey or projection of a canal, as we now are, to explain a limitation which ought to be attended to in all such level-cutting, especially if of any considerable length, viz. that the height or level of the canal should be so contrived, that in any cross section, as *fig. 1*. the sum of the areas of A B C E and L I K P shall just be equal to E F G L, the part excavated or dug. It will readily be perceived that

figs. 4 and 6, are indeed other cases of level cutting, occurring wherever the principal engineer has, in crossing a vale, or point of a hill, found it necessary to preserve his level above or below what would otherwise have been desirable, if to be accomplished, as in our first case. The engineer will find abundant instances of *figs. 1, 4, and 6*, in all their degrees, and in a great portion of which there will either be a want of stuff to form the banks, as in *fig. 4*, or a redundancy from the deeper cutting, as in *fig. 6*, and the perfection of his skill will be shewn in so conducting the line, that every embankment, as *fig. 4*, shall have deep-cutting at both, or at least at one of its ends, to furnish the extra stuff, with the least expence in moving it; in like manner, every deep-cutting, as *fig. 6*, should have embankments at one or both of its ends, to receive the extra stuff. It is further evident, that the other three cases, viz. *figs. 2, 3, and 5*, are but varieties of side-lying ground, or wherein the canal is conducted along the side or slope of a hill; and where it is evident, that a proper choice of the situation of the canal, higher up or lower down the hill, may occasion *A B C E* and *L I K P*, the banking in *fig. 2*, together to be exactly equal to *E F G L*, the digging in this case; in like manner, where the slope of the hill is so considerable as to admit of no upper bank, as *fig. 3*, the bank *A B C E* may be equal to the cutting *E F G I K P*; it may be on a considerable slope that embanking is required, as in *fig. 5*, in order to preserve the most direct line, or to reach any particular object; or deep-cutting may, and often does, occur in sloping ground, and not in level, as we have shewn in *fig. 6*, but it seemed unnecessary farther to multiply our cases to delineate such varieties. An attentive reader will find no difficulty in tracing every possible variation, by considering the line *A' P'*, which represents the ground to vary in all degrees both of height and inclination, while the banks and canal, *A B C F G I K P*, remain fixed; and in this, almost the simplest inquiry that occurs in such a work, it cannot fail of appearing, how essential a good knowledge of mathematics is to every engineer, and that none ought to be admitted to that honourable distinction, who are unlearned therein, however much they may have seen, or even executed, under the orders of abler men.

Our second and third cases requiring more than ordinary consideration, before the line of the canal can be definitively settled, and the ground be marked out and purchased, unless waste is committed, in purchasing more than the company have occasion for; we have repeated them again in *figs. 7 and 8*; and therein produced the lines of all the banks, by which the situation of the level-peg, of which we have spoken above, is shewn at *a*. It is also evident, that the lengths and positions of all the lines, *BC, CF, FG, GI, and IK*, being given, as also the positions of the lines *BA, KP, and A' P'*; that the areas of the several triangles *a BC, b FG, b CI, c IK, e Fg, and e CK*, and of the parallelogram *IKgG*, are known; and the calculation of these several triangles will generally, in practice, be very easy, from the consideration of their being all similar and isosceles. It is further evident, that the triangles *a EA, b EL, c PL, b Ec, and f EP*, are in general similar: from such considerations, theorems can be deduced, shewing, in every case, the distances *d L* and *d E* of the slope-holes, or edges of the cutting *L* and *E*, *fig. 7*, from the level-peg *d*, or of *d E* and *d P* in *fig. 8*; as likewise the distances *d I* and *d C* of the top edges of the canal, measured upon the level, from the level-peg; so that the stuff to be dug may just form the banks. The distances *d A* and *d P*, *fig. 7*, and *d A*, *fig. 8*, that determine the points *A* and *P*, at which the banks are

to be begun, are also easily deducible from the same considerations; and it is evident, that *A P* is the width of ground that ought to be purchased, except in such cases where a hedge may be necessary at *P*, or, as may sometimes be advisable, a hedge at the bottom of the slope at *A*, instead of its top *B*, when the necessary width for one or both of these hedges must be added to *A P*. The investigation of theorems for the above purposes, and others which we shall have occasion to mention, would lead us farther into the subject than would, perhaps, be proper, especially as no person ought, in our opinion, to undertake or meddle with the direction of such works, who is not only capable of using a theorem laid down by another, but of investigating and preparing rules for every case that can occur, or be wanting in his own practice. We proceed, therefore, to advise the resident engineer, on being furnished with the dimensions that the canal and its banks are to have, to calculate tables for readily finding the distance *d h* of the level-peg from the middle of the canal, measured on the slope of the hill, let the hill slope with whatever angle it may; or rather, let the angle *i d h*, or depression of the slope below the horizontal line *i d*, be what it may; and this will be most conveniently expressed, not in degrees, but by the natural lines of the angle of the depression; because then, if a measuring chain of 100 links be laid down at length, upon the slope of the ground, and the difference of the level of its two ends be taken in links by the spirit-level, these will express the two first figures of the natural lines of the depression, which is quite as great exactness as such tables need be calculated to. The engineer will now proceed to put in a stake opposite to each level-peg, at the proper calculated distance down the slope, for the approximate or supposed middle line of the canal: these stakes will seldom be found for any considerable distance together, to range in a straight or in any other regular line, that will be proper for the canal: and a very difficult and nice part of the engineer's duty is now to be performed, in staking out a new line with a taller or a quite different set of stakes from those formerly used, to avoid confusion; this is called staking the middle range of the canal. The requisites in this new line or range for the centre of the canal is, that it should as nearly coincide in every part with the stakes that were last put in by the calculation, as possible; that, where, in order to preserve a regular and handsome line, and avoid the awkward, inconvenient, and unmeaning crooks and bends, with which too many of our canals, and even some of the latest construction, are almost in every part disgraced, the line is conducted higher than the calculated stakes for one or more stakes together, care must be taken that it shall quickly be conducted below others, so that the redundancy in cutting deeper into the hill in one place may be as exactly as possible balanced by a deficiency just by, owing to the line being conducted below the level-stakes. Besides the consideration above, it will be the time now to estimate and consider the quantity of stuff that will be wanted to land up every bridge and lock, and to give extra thickness to the banks on which any toll-houses, warehouses, or other buildings, are to be erected, or trade carried on.

In narrow canals, or branches of that description, it will be necessary to provide for wider places at short intervals, for barges to turn, and to lie in while others pass them; considerable skill and care are requisite in the choice of proper places for such purpose: they ought to be so situate that barge-men can mutually see each other approaching on narrow canals or branches, and provide for passing, without either of them having to drag their barge back again to a passing-place, as too often happens; at the same time, they

ought to be chosen, if possible, in such hollow or low places as will admit of widening the canal without much extra expence. Another consideration is, the excavation of basons, docks, or wharfs, from which stuff may accumulate, which ought to be used up, if possible, in embanking the line just by. Many canal companies have seen it their interest, on proper and timely application from land-owners, who were desirous of erecting wharfs, to direct their engineer to calculate upon, and to excavate the additional width necessary for such purpose, at the company's expence; this and the extra or deeper cutting that there must always be, in the approach to a lock on the lower side, and of embanking on the same approach on the upper side, should also be well considered and accurately calculated; and full and explicit memorandums ought to be entered in the engineer's field-book at the time, where the stuff was calculated to be had from for every embankment, and where the stuff is to be disposed of from every deeper cutting or extraordinary excavation. These memorandums will prove of the most important use in the revival of the whole length of line or district that is about to be fixed; as also, in contracting for and letting of the work afterwards, by being able, without fear of mistake, to point out which way every part of the stuff is to be thrown or wheeled, as fast as it is dug, and that no part of the same may want moving a second time, or any wide or gouty places be made to disfigure the canal for finding stuff; or, what is often of more fatal consequence, the canal being dug deeper than usual for such purpose.

After the line shall have been thus marked out with the utmost care, it will still be prudent for the engineer to revise it again, and to make pretty accurate calculations of the quantity of stuff wanting, or to spare in particular places; in these kinds of calculations the engineer will find the most important aid in a ready use of the *slide-rule*; and we beg here to mention that a gentleman who has long distinguished himself by the various and important uses to which he has made the slide-rule subservient, has prepared a short but complete tract on its application in the concerns of an engineer, which it is hoped that he will ere long publish. Perhaps, on the review of the line, the curves or bends thereon may in some cases be eased, and beauty and convenience may be more fully attained without much, or often any extra expence. The *Droitwich* canal has been mentioned as one on which these points have been the most fully attended to. The portion of the canal that has been thus staked out and revised, may now have the boundary lines marked out of the land to be purchased; and the surveyor should proceed without delay to survey the same, and to treat with the owners for the purchase, as we have before mentioned. It will be among the first works to dig out for the foundations of the locks, if they are not already in hand, and for the bridges, if the season of the year and supply of bricks and work-men will admit of their proceeding immediately: the several drains or culverts that are to pass under the canal should also be dug out, and prepared for the masons or bricklayers, and the several safety-gates, stop-planks, weirs, and other erections, which we shall notice more particularly further on. It may be proper here to caution the engineer, that in case the pipes of any water-works, or that supply any gentleman's house, cross the line of the canal, such pipes should be laid at once, two or three feet beneath the bottom of the intended canal, with an easy descent and ascent therefrom, and the ground be made good again as soon as possible, both to prevent their being damaged in cutting the canal, and being exposed to frost, or to thieves, if of lead, by lying bare; and in case such pipes are found old or decayed, new ones of lead or cast iron

should by all means be laid in the deep part under the canal. The top-soil should be carefully removed; and in order to determine readily and correctly the places of the slope-holes at E and L, *fig. 7*, and E and P, *fig. 8*, the engineer will find it useful to calculate the distances of d E and d L, and d P, by a general theorem, in terms of d h and h i, and to make tables for the several values of those data, that are likely to occur. The values of d P and d A, *fig. 7*, would be alike useful in a table for determining the limits of the banks that are to be raised.

Before cutting out the lock-spit, or small trench between the several slope-holes, as a guide to the men who are to dig, the engineer ought to cause holes to be dug in the line of the canal, near every second or third level-peg, or oftener, if the soil be variable, in order to prove the soil to a greater depth by two or three feet than the cutting of the canal is to extend; and each of these the engineer ought carefully to inspect, in order to determine what puddling or lining will be necessary; and what will be the difficulties of digging, owing to the hardness of the stuff, or to water that must be pumped out, &c.; all which circumstances, as well as the extra distance that any part of the stuff may require to be moved, must be well considered before the work can be let to the contractors or hag-masters.

The *puddling* or *lining* of a canal, to make it hold water, is a matter of the greatest importance, and we shall consider five cases, in *figs. 9, 10, 11, 12, and 13*, that are likely to occur or present themselves in the search, into the soil that is to be dug, by sinking holes as above mentioned: the first case we suppose to be that in which the whole is clay, loam, or other water-tight stuff, as shewn by the dark shading in *fig. 9*: all soils that will hold water, and not let it soak or percolate freely through them, are called water-tight. Our second case, *fig. 10*, is that in which the whole cutting will be in sand, gravel, loose or open rock, or any other matters that will let water easily through them, and such are called porous soils or stuff. The third case we suppose to have a thin stratum of water-tight stuff on the surface, shewn by the dark shading in *fig. 11*, and to have porous stuff for a considerable depth below, here distinguished by dots. The fourth case may have porous stuff near the surface, and water-tight stuff at the bottom of the canal, as in *fig. 12*. The fifth case is that where water-tight stuff appears on the surface, as *fig. 13*, below this a stratum of porous stuff, but having again water-tight stuff at no great distance below the intended bottom of the canal. The new raised banks that are left unshaded in all the five figures, are always to be considered as porous stuff, as indeed they will always prove at first, and in a great portion of soils they would ever remain so, unless either puddling or lining was applied; all ground that has been dug or disturbed must also be considered as porous. It should also be remarked that any kind of soil which is perforated much by worms or other insects, should in canal-digging be considered as porous stuff. *Puddle* is not, as some have attempted to describe it, a kind of thin earth mortar, spread on places intended to be secured, and suffered to be quite dry before another coat of it is applied; but it is a mass of earth reduced to a semifluid state by working and chopping it about with a spade, while water just in the proper quantity is applied, until the mass is rendered homogeneous, and so much condensed, that water cannot afterwards pass through it, or but very slowly. The best puddling-stuff is rather a lightish loam, with a mixture of coarse sand or fine gravel in it; very strong clay is unfit for it, on account of the great quantity of water which it will hold, and its disposition to shrink and crack as this escapes; vegetable mould or top-soil is very improper, on account of

the roots and other matters liable to decay and leave cavities in it, but more on account of the temptation that these afford to worms and moles to work into it, in search of their food: where puddling-fluff is not to be met with, containing a due mixture of sharp sand or rough small gravel stones, it is not unusual to procure such to mix with the loam, to prevent moles and rats from working in it; but no stones larger than about the size of musket bullets ought to be admitted. That the principal operation of puddling consists in consolidating the mass is, we think, evident, from the great condensation that takes place: it is not an uncommon case, where a ditch is dug, apparently in firm soil, that though great quantities of water are added during the operation, yet the soil that has been dug out will not more than two thirds fill up the ditch again, when properly worked as puddle. It should seem also, that puddle is rendered by that operation capable of holding a certain proportion of water with great obstinacy, and that it is more fit to hold than transmit water. It is so far from true, that puddle ought to be suffered to get quite dry, that it entirely spoils, when by exposure to the air it is too much dried; and many canals which have remained unfilled with water during a summer, after their puddling or lining has been done, have thereby become very leaky, owing to the cracks in the puddle-ditches and linings. One of the first cares of an engineer, when beginning to cut a canal, is to discover whether good puddling-fluff is in plenty, and if it be not, it must be sought for and carefully wheeled out or reserved wherever any is found in the digging; or perhaps procured at considerable distances from the line, and brought to it in carts. It has happened in some stone brach or loose rocky soils, that all the puddling-fluff for several miles of the line, required to be brought to it; but even this expence, serious as it may be, ought not to induce the copying of those, who have left miles of such banks without any puddling, and have made a winter canal, but which no stream of water that is to be procured can keep full in the summer months. It is usual in canal acts to insert a clause for the security of the land-owners, to require the company to cause all the banks that need it to be secured by puddling, to prevent damage to the land below by leakage: and it would have been well for all parties in many instances, if this clause had been enforced. It appears that the Dutch have been in the habit of making mud-ditches to secure the banks of their canals and embankments, from time immemorial; and that operations similar to our puddling have been long known on the continent, but it is not clear at what period it was introduced into this country; we think that the fens of Cambridgeshire and Lincolnshire, in which so many works have at different times been executed by Dutchmen, are the most likely places in which to search for early evidence of its use. We cannot think that *James Brindley* was the first who ever used it in this country, although we might admit that the *Bridge-water* canal was the first in which it was systematically used as at the present day. If we compare our first, fourth, and fifth cases, *figs.* 9, 12, and 13, we shall find in all of them a water-tight stratum as the basis; and the practice in these cases is to make a wall of puddle, called a puddle-ditch, or puddle-gutter, within the bank of the canal, as shewn in section, by *ac*, in the above figures; these puddle-gutters are usually about three feet wide, and should enter about a foot into the water-tight fluff, on which they are always to be begun: and they should be carried up as the work proceeds to the height of the top-water line, or a few inches higher. Our second and third cases, *figs.* 10 and 11, evidently will not admit of the above mode, because we have here no water-tight stratum on which to begin a puddle-gutter as a

bottom: in these cases, therefore, it is usual to apply a lining of puddle to the sides and bottom of the canal, as shewn by the cross shading in *figs.* 10 and 11: the process of puddling and lining will occur more properly further on, as we proceed in describing the operations of digging and forming the canal.

In order to describe more intelligibly the process of setting out and digging a canal, in the two cases where puddling or lining will be requisite, we have repeated our first and second case, but on a larger scale, in *figs.* 14 and 15; wherein *p* is intended to represent the hole that has been before supposed to be sunk, in order to prove the soil; and, according as this terminates in water-tight or porous fluff at its bottom, that puddle-ditches, *q c f w* and *x e f t*, *fig.* 14, or a lining, *q r f t H G F D*, *fig.* 15, is to be applied; *D H* being the height to which the water is to stand in the canal. The engineer will in the first case determine the place of *E* and *L* on the ground, and dig small holes or nicks to mark the same, called slope-holes; but in the second case other marks must be made at *n* and *v* about five feet from the former, to direct the beginning of the cuttings, with allowance for the lining. A skilful and very handy workman is now required to mark out the line upon the ground, called the lock-spit, between the slope-holes at *E*, *fig.* 14, above-mentioned, which we have supposed to be made at about two or three chains from each other. This is done by laying down and stretching a strong line upon the ground, between two or more adjoining slope-holes, and if the canal is not to be straight in that part, with small pegs to give it the gradual and regular bend in every part that the canal is to have; the workman then proceeds, holding his spade or grafting tool not upright, but always with the slope *C E*, that the bank of the canal is to have, and strikes it successively into the ground close to his line, until the whole length of the line is marked out; by this means, if the ground has sudden undulations, or hollows, as continually happens, owing to the ridges and furrows of cultivated lands, and other causes, yet a regular line coinciding in every part with *E* is marked out upon the surface; before the line is taken up, another labourer follows on the other side of it, and strikes in his tool inclining the contrary way, by which a triangular sod or piece of earth is cut and thrown out: a similar lock-spit must be cut on the other side of the canal at *L*; and the same at *n* and *v* in *fig.* 15. If neatness and regularity are properly consulted, lock-spits for the extremities of the banks at *A* and *P* will also be proper, especially if the land *A N* and *P P'* is valuable, and the damage by the scattering and laying of the fluff would be considerable. The engineer has now to determine, in *fig.* 14, the points *c* and *d* for the beginning of the puddle-ditches, and these he ought to choose such, that if the same were carried upright to the top-bank, *b C* or *L n* would be about one foot: if this is not strictly attended to, the labourers or navigators, as they are called, will for their own convenience begin their puddle-ditch much too near the canal at *E* and *L*, in some cases, and not make it upright but hatching back to arrive at *ab*; and puddle-ditches so made are apt, owing to the settling of the bank, to get broken and be spoiled. It may be proper here to remark, that canals set out with the scientific precautions and care that we have recommended, will always have the proper quantity of fluff to allow for the settling of the banks, because $\triangle B C E + \triangle I K P = \triangle E F G L$, in the same settled or consolidated state, that the latter part was before the digging commenced: it will, however, be proper to give the contractors a table or rule shewing, according to the height, as *ac*, what extra height a suddenly raised bank is required to be, to allow for settling: and it is evident that

the slopes of such banks must be steeper in the first instance, than they are intended ultimately to be.

We may now suppose the engineer to proceed to the letting of the cutting of certain lengths of the canal to contractors or hag-masters, who will employ a number of navigators under them, in digging and puddling the canal. It is usual to let the work at a certain price per cubic yard of digging, and to pay for the puddling and lining either at a certain price per cubic yard, or per yard run of the canal. The engineer ought to inform himself thoroughly on the difficulties and facilities which attend the work he is about to let, and to draw up a short but explicit contract to be signed by the contractor. We cannot but recommend that all contracts for material or large jobs of work, not only in cutting, but for the mason's, and other works in particular, should be submitted to the principal engineer for his approbation, before they are signed or finally concluded on. The prices allowed ought to be fair and liberal, according to the circumstances, so that the contractor may have no pretence on account of low prices, to slight his work, particularly the puddling; and they ought in every instance to be strictly looked after, and made to undo and renew immediately, any work that shall be found improperly performed. We recommend it to the engineer to keep a strict account, by means of his overseers or counters, of all the men's time that are employed upon the works; distinguishing particularly the number upon each work, and whether employed by the day, under the company, or upon the work that is let to contractors. These particulars are most essential towards knowing, what money ought to be advanced to the contractor during the progress of his job, and towards informing and maturing the judgment of the engineer, in the length of time that a certain number of men will be in performing any future work that he may have to direct; and a calculation ought to be made in every instance of the day-work, and compared with the contract price, by which alone a correct judgment can be formed of the proper prices at which work ought afterwards to be let, so that the labourers may receive proper wages, proportionate to their exertions, and the contractor be amply paid for his time, skill, and superintendence; and yet economy and the interest of the company be duly consulted. Barrows and wheeling-planks, horsing-blocks, and other implements, are generally found by the company; and it is usual to consider 20 to 25 yards, to be a stage of wheeling, and a price per cubic yard to be fixed, according to the number of stages that soil is to be moved: where this distance exceeds 100 yards, it will not often be eligible to perform it by wheel-barrows; and runs of planks with an easy descent, if the same is practicable, should be then laid for large two-wheeled barrows, or trucks to be used thereon.

The cutting of a canal being let, the work is usually commenced by a labourer, on the part *Eg*, *fig. 14* or *15*, on the lower side of the canal; and from the lock-spit at *E* he marks out a certain width to *g*, such that he can throw or cast the stuff as he digs it, on to the part *Ac*, and so that the heap may not obstruct the intended puddle-gutter *cd*. The side *EF* he is careful to cut down in the proper slope of the bank; the other side is usually cut straight down, and this work is continued until he comes to the bottom of the intended canal at *Fb*, and this space *EFbg* is called the "reaching." The same process is followed on the lower side of parts that want lining, as *fig. 15*, except that *nrbg* is the reaching in this case, and that there is no necessity to throw the stuff further in this case, than that it may lie upon *nA* without rolling back into the work; and it is usual, if the reaching will not be very deep, to lay two or

three rows of fods or sound spits of earth, with regularity in the face of the slope *nq* to form part of the bank, and to throw the other stuff over these. Reachings are also to be dug on the upper side of the canal, as *ikGL*, or at least as much stuff is to be thrown out therefrom as can conveniently be stowed upon *dP* and *vP*, *figs. 14* and *15*.

It is now time to commence the puddling in *fig. 14*, and a labourer begins by digging out the bottom of the intended puddle ditch *cesd*; if the soil dug out is good puddling-stuff, he lays it on the part *dE*, if otherwise he throws it at once on to the heap on *Ac*. A careful examination of the face *EF* of the reaching will shew to what depth the puddle-ditch *df* ought to be carried in every part, to reach and intersect any faulty places, or veins of lighter soil, or worm, rat, or mole-holes that may accidentally occur in the bank. After the puddle-ditch is dug clean out to its proper depth, and this is a circumstance that the engineer or some careful overseer ought always to look particularly to, about 9 or 10 inches thereof is to be filled loosely up with puddling-stuff, either from that which comes out, or from the nearest heap in reserve, all large stones, sticks, straws, or other extraneous matters being carefully picked out as the stuff is sprinkled in: by this time, unless the season is very dry, it is probable that some water will be collected in the bottom of the reaching *Fb*, and this should be laded out with a scoop into the puddle-ditch, so as to give the stuff therein a good wetting; if the puddling-stuff be of the stiffer kind, or was very dry, it will be right for the labourer to betake himself to some other part of the work for two or three hours, but perhaps giving his stuff another sprinkling of water in the interim; he may then proceed with the puddling; and for this purpose he ought to be provided with a stout pair of puddling-boots, that will keep out water; he begins at one end of the trench, and keeps chopping with his tool into the stuff and quite through it, giving his tool a lunging motion every time before it is withdrawn, so as to let the water into and to stir every part of the puddling-stuff; if more water is wanted, another labourer is set to lade it out of the reaching as before; and the puddler thus proceeds, chopping down at every inch or thereabouts as he slowly advances, and trampling about at the same time as much as he can with his feet, which greatly assists the operation: when arrived at the end of the trench, he returns and repeats the same operation, until every part of the puddle is properly worked; which is known by the tool going equally easy into it in every part, which it would not do if any dry lumps remained, and the whole being in a semifluid state; giving the puddling-stuff just the due quantity of water is very essential to its working well, and this, experience will soon point out.

Very great care and management will, in general, be required on the part of the engineer, to furnish water for the puddling: it will often require to be brought in temporary trenches, perhaps across several fields from some mill-dam, large pond, or spring of water above the canal; for which purpose general powers ought to be given in the act, upon condition of levelling and making all such trenches good again as soon as possible, and paying for the damage; often times puddling water is not to be had without pumping it up, and conveying it considerable distances in troughs, of which great numbers will be required. It will very often be requisite to convey the water across the canal in troughs to the different puddle gutters, and plenty of trestles should be in readiness for supporting these troughs at the requisite heights. Considerable care will be necessary to turn off the surplus water, into some channel where it can run off without flooding the works; or to stop it at its source; this last ought always to be adopted, when the supply is not very

plentiful, or the owner of the stream or pond might be injured by taking a confluent stream from him, during the progress of the work. The first or bottom course of puddle being properly worked as above, it should then be suffered to stand two or three days undisturbed, and without any more water being given to it; when it will be found sufficiently set that a man may step on to it without sinking in; it is then ready to receive a second course; the first step is to scrape off and remove any lumps of earth, stones, sticks, or other matter which may have fallen in to the puddle-ditch; about 10 inches thick of puddling stuff is then to be sprinkled lightly into the ditch as before; and water is to be applied either from the reaching, or from some of the troughs which we have been mentioning: some hours time is to be allowed for the stuff to soak, unless it be light loam, and moist at the time of putting it into the ditch; in such case, the puddling may be begun almost immediately: care must be taken that the tool be made to penetrate a small distance into the old puddle at every chop, in order that the two courses or layers may be properly incorporated. After this course is properly wetted and worked, it must stand the proper time to set as before, but by no means to get dry, otherwise it will be found full of cracks and must be worked anew: and in case, owing to any temporary suspension of the work, it should be necessary to leave a puddle-ditch before it is finished, it ought always to be covered, and left with a dry or unworked course of puddling-stuff upon it, to keep the air from it, and preserve the proper moisture in it.

When a sufficient number of courses of puddle have been added, to fill up the ditch *cefd*, two or three rows or courses of fods, or spits of earth, must be laid on each side, to raise the ditch so much higher; at the same time that the heap of stuff on *Ac* is levelled down, and other stuff is brought by the men, who are wheeling from the bulk *gbki* that is left in the middle of the canal, and laid on *dE* to back up the spits or fods: after cleaning the surface of the puddle, if properly set, it will be ready to receive another course of puddling-stuff, the water must be turned on, it must have time to soak, if necessary, and then be worked and stand to set as before: other rows of spits of earth may then be laid, to raise the sides of the puddle-ditch, and the bank may be made up to the same height by fresh stuff wheeled in from the canal; and care being taken to lay spits of earth to form the slopes *AB*, and *EC*, as the works proceed upwards, particularly the inside slope *CE*, which should be well trod and consolidated by strokes of the tool to prevent its falling down, or being disturbed by the water when the canal is filled; another course of puddling-stuff is then to be added, and all the same process gone through till the puddle has arrived at *qæ*, the height of top-water, or an inch or two higher, which being properly set, the bank is to be made up, covering the puddle completely up with common stuff, to the intended height of the top-bank *BC*, with proper allowance for the settling; and observing that the puddle will not settle near so much as the other stuff, if at all. The process is no way different, by which the other bank *LIKP*, and its puddle ditch, are to be carried up, and completed to the intended height. The part of the canal, with puddle-gutters, *fig. 14*, of which we have been speaking, has, in general, a lump or ridge of stuff remaining in the middle of its bottom, until the very last: a different system ought, however, to be pursued with such parts, *fig. 15*, as require to be lined; here the banks *ABqn*, and *viKP* may be at once made up, and the whole of the space *nrsv* ought to be cleared for certain distances, before the lining of the bottom can be begun. A great deal of management is required by the overseer or contractor, to manage all these

parts of their business, so that there is no hindrance of any part of the work, that every man is provided with stuff by the wheelers, when he wants it to make up his banks or to puddle, and that the parts to be lined are cleared in time. To accomplish all these objects, a good part of the stuff cannot be wheeled directly out to the nearest or opposite points of the bank, but it must be worked forwards and backwards obliquely, on the runs of wheeling planks by the wheelers, as occasion may require. It may often be necessary to exceed one or two, or perhaps more, stages of wheeling, to avoid taking out the stuff and clamping it, by which it would require filling again, damage would, in most cases, be incurred on the adjoining lands, and frequently the puddling and working of the banks would be impeded, by crossing them to land the stuff.

A length of the canal that is to be lined being cleared, and the bottom levelled and cleaned smooth down to the line *rs*, a course of puddling-stuff about 10 or 12 inches in thickness is to be spread over it, with all the precautions, to extract extraneous and hurtful matters, which have been before given, and the whole is to be wetted and allowed to soak if necessary, as before: the working of this puddle is now to be begun; and as the extent will generally be large, several men may be employed, at once, upon it, so as to make it worth while for an overseer employed by the company, to attend them constantly to see that no part of the work is slighted: as the bottom in this case is supposed to be sand, loose rubble of a rock, chalk, or other matters, that would injure the puddle if mixed therewith, we have recommended a thicker course at first than is usual of puddling-stuff, and in working the same the men ought not to strike their tools deeper or even quite so deep as the bottom of the puddling-stuff to avoid disturbing the bottom. When this course of puddle has been allowed to set, another course of about nine inches is to be added, and treated as before, till about three feet of puddle is added, if the soil is very porous; and the top course being set, a course 18 inches or two feet thick of the common soil or stuff should be laid evenly upon it and the bottom levelled; this covering of the bottom should be rather dry, and not in large lumps, or with great stones or sticks in it.

The lining of the sides is now to be proceeded with as follows; the top covering of the bottom should be removed for three feet in width next each of the sloping banks; and the surface of the puddle be carefully cleared of dry lumps, stones, &c.; a thickness of nine inches of good puddling-stuff is now to be laid in this place and wetted and worked, and allowed to set as before directed, when another nine inches is to be added in like manner; some common stuff from the digging of the canal is then to be brought in spits or fods, and carefully piled up for two feet in width, and about nine inches in height, hatching-back before and behind, agreeable to the slopes *FE* and *GL*, and leaving a space or puddle-ditch behind, next to the sides *rn*, and *sv*; the surface of the puddle at the bottom of these is to be carefully cleared, nine inches of puddling-stuff applied, wetted, worked, and allowed to set as before: more spits or fods are then to be piled in the front, as a facing to keep up the puddle, and their interstices should be filled with fine stuff to make the whole solid; when puddling-stuff is again to be applied behind, and the same process repeated till the puddle and facing arrive at *qD* and *HA*, when the remainder is to be made up with dry stuff and spits to the top-bank level at *C* and *I*, as directed in the former case.

The last of these ways of making a canal water-tight is the more tedious and expensive of the two; it is however general, and may be applied in any situation with perfect

success. Mr. Thomas Telford, in *Plymley's Agricultural Report of Shropshire*, 8vo. p. 296, when speaking of the *Shropshire* canal, says, "This canal, carried over high and rugged ground, along banks of slipping loam, over old coal-mines, and over where coal-mines and iron-stone are now actually worked under it, is a satisfactory proof that there is scarcely any ground so difficult but where, with proper exertions and care, a convenient water conveyance may always be obtained." And we have heard of instances of canals being conducted over ground so rocky, and abounding with such great chafms, and loose pieces of rock, that many yards together of the canal bottom might have fallen in, had not the precaution been first taken, of removing all the smaller and loose stones and rubbish, and wedging in the large loose pieces of rock with stones, set in mortar, and thus rendering the foundation sound, on which soil to fill up the inequalities, and a lining and facing was applied as above, with perfect success. We have already observed, that some persons have thought it right to omit puddling or lining, where springs appeared in the bank of a canal; and the matter is of so much consequence, that we beg farther to observe, that the appearance or non-appearance of springs ought in general to have no effect in determining the propriety of these essential measures; if a spring is of any use to a canal it will rise, owing to the puddle-ditch or lining, and run over the same into the canal, and no water will be thereby lost; and if it will not so rise, it may safely be ranked as a drain of the most mischievous kind, instead of a supply, and therefore very essential to be stopped up.

In case it is found that there is stuff to spare after completing the banks, it will sometimes be advisable to remove the top-soil from A' A in low places, and after spreading the extra stuff so as to make the ground good, to return and spread the soil on it: the part P P' will often admit of similar treatment, and sometimes sudden hollows there may be filled up, so as to have a fall to the top-bank I K, and avoid a deep ditch through an adjoining swell or rise of the ground at P, to carry off the rain water to a culvert where it is to pass under the canal: where it happens that P P' is waste or ground of little value, or the company is possessed of a piece that they have been obliged to purchase and cannot readily dispose of, it may be proper to make a heap or spoil-bank of any extra-stuff, to be afterwards heated away as occasion may require. If a deficiency of stuff is experienced to complete the banks, the part P P' furnishes a good resource in many instances; the top soil being removed on the higher parts, an excavation like P y P', *fig. 14* and *15*, may, and indeed must in many instances, be made with a proper fall for conveying the rain-water that falls in every part above the canal to the brook or culvert that is to take it off; the slope P' y ought to be so easy, and the top-soil so spread, that the land shall be as fit for agricultural purposes afterwards as before. Another resource ought in an earlier stage of the business to be provided, in the deep-cutting, by marking out a yard or two or more width of ground to be purchased on the upper or deeper side, than is actually wanted, by which a great deal of stuff may be procured at a comparatively small expence of land: it must be evident, that the resources we have pointed out above are inadequate to receive any great redundancy, or to supply any great deficiencies of stuff, and are only sufficient where the canal has been set out with scrupulous care; bungling, or careless canal-makers must be content to leave lasting marks of their incapacity or folly behind them, in the many sudden bends into the hill that they are obliged to make to obtain stuff, and out of it to dispose of the same in other places, with numerous wider or deeper places on the canal to make

up the banks, or in enormous spoil-banks or useless excavations. Where a reserve of stuff has been made in the deep-cuttings at several points on each level or reach of a canal, as above-mentioned, it will be the better fault of the two, to experience a deficiency of stuff; because as soon as the bottom of the canal has been cleared, and the lining of the bottom and sides for some height performed, or the puddle-ditches carried up, the canal may have 18 inches or 2 feet of water let into it, and dirt-boats may be used to carry stuff from the deep cuttings to make up the banks in other places; whereas all redundant or spare stuff must be got out before the bottom lining can be applied, or any effectual use made of boats to move stuff from place to place; and the same advantages will be experienced in situations where puddling-stuff is only to be procured at particular points on the line, by clearing out and completing the bottom part of the canal for considerable lengths, so that dirt-boats may be used to bring the same for the puddling or lining of the upper part of the banks, which, if there is spare stuff, cannot be effected without heavy expences in moving the same and forming spoil-banks. Where the line of a canal is to cross an extensive stratum of valuable brick earth, or one of good gravel for making of roads, it will often be advisable, especially if the line can be rendered more direct thereby, when setting out the canal, to cut pretty deep into such materials, and even quite through the gravel, if the same is practicable, as might have been done at Dawley-deep, between Paddington and Uxbridge, on the *Grand Junction* canal; for although considerable expence will in the first instance be incurred in digging and in damage for spoil-banks, yet such materials, as good brick-earth and gravel, will in almost every instance find a market as soon as the canal is opened; such a situation of the canal may prove of essential service to its trade, by enabling the adjoining proprietors to work the whole thickness of their brick-earth, gravel, or other useful matters, and destroy but very little of the surface of the ground, and without being annoyed by water, but which the canal would catch in very considerable quantities perhaps, instead of losing water by preserving a high level through porous stuff. It is highly to the interest of a canal-company to give facility to the getting and conveyance of all useful articles within their district, at the cheapest possible rates, as the only means of opening new sources of trade or manufactures, by which their concern will be in the most essential degree benefitted. In districts where stone and gravel for making and repairing of roads are scarce, it will be proper to pay the labourers certain rates per cubic yard for all the stones or gravel that they may collect out during the work, and slack in proper places; as resources for the making of the towing-path C I, *fig. 15*, and for making good the landing or ascent to the several bridges, and the several pieces of new road that the engineer will have to form, near to the canal and bridges; the lock-banks and all wharfs and landing places should also be covered with good gravel to render them safe and convenient for use: if good gravel can in places be interdicted in deep-cuttings, much of the above expence, as well as of cartage, may be saved, by an early use of dirt-boats in the bottom of the canal. It cannot, we think, have failed to strike every reader ere this, how very important and various the duties of the resident engineer are; but the same will be much more apparent, when we shall have finished, in the following pages, the more particular observations that occur to us under the heads of reservoirs, feeders, aqueducts, embankments, culverts, safety-gates, weirs, tunnels, deep-cuttings, locks, substitutes for locks, inclined planes, rail-ways, bridges, towing-paths, fences, drains, boats, towing or mov-

ing boats and trams, cranes and implements, &c. of which we shall proceed to treat; after observing, that none but men of the strictest integrity and extensive knowledge ought to be employed as resident engineers, and that the committee and principal engineer ought not to hesitate in offering and paying such men a very liberal salary, to engage the whole of their time; and, that too great a length of line or extent of business should not be put upon such a man. This is the proper sphere, where young men or others, of knowledge and persevering industry, who are coming forwards in their profession, should exercise and give specimens of their abilities as engineers; and it will prove of the utmost importance to such, as well as to a company who have an extensive line of canal to construct, to employ more than one of such men at the same time, upon adjoining lengths of the canal; where their emulation may be excited in an honourable contest, as to those who shall execute their portion of business in the most complete, orderly, and economical manner.

One of the first considerations relating to the *construction of a Reservoir* for supplying a canal, is the supply of water that is to be expected for it, and in what proportions at different times of the year: for this purpose we suppose the engineer to be furnished with an accurate survey of the vale or vales that lie above the intended reservoir, so as to be able to calculate exactly, how many square miles and fractions of surface drain towards or vent their rain-water through the part intended to be embanked for the reservoir; it will be very proper also to be furnished, if possible, with the exact gauge or quantity of water that has actually in former years been discharged by the brook or stream that is to be embanked; as also with the quantity or depth of rain which usually falls within the drainage of the intended reservoir. If the length of time that has elapsed, since the situation of the reservoir has been determined on, has not allowed of careful and accurate experiments being made on these points, the engineer must assume them from the best data that the information of millers and other persons will afford, and the printed tables, or journal of rain, kept by curious persons in the nearest similar situations, must be consulted: it is particularly necessary to attend to this last circumstance, because there are, we believe, instances of places where the annual depth of rain does not amount to a foot, and others in which it exceeds five feet; while 23 inches is about the medium depth of rain annually, at or near London. The most perfect method of obtaining true information on this subject, is to gauge the different springs or streams, from whence the supplies of water are to be derived, and thus to ascertain the exact surplus, after the mills are amply furnished. In the great contest about the Rochdale canal, Mr. Rennie had all the streams, which could be affected by the proposed reservoirs, gauged for about a year. He first ascertained the state of these streams at a time when the mills were amply supplied with water, and had proper gauges fixed upon them. The daily difference was measured, and the surplus thus ascertained amounted in the year 1793 to sixteen times the ordinary produce of the rivers. The evaporation that takes place, from a given surface of water in different places, has not yet been so accurately observed as the importance of the subject to canal engineers deserves: Mr. Bevan's observations thereon, at Leighton-Buzard in Bedfordshire, continued for five years, to the end of 1804, gave an evaporation of 22.92 inches at a medium per annum, while the depth of rain there, in the same period, was observed to average 23.28 inches; in some years the evaporation considerably exceeded the depth of rain, and in others it fell as much short of it or more. On this subject, see the article *EVAPORATION*.

It will sometimes happen, that the valley in which the reservoir is to be made, has other valleys parallel to it, on one or both of its sides, such, that by beginning a fough or small tunnel above the level of the reservoir, continuing it with a small rise through the adjoining hill, and from its further end continuing a ditch or feeder along the side of the hill rising gently as it proceeds till it intersects the bottom of the vale, a brook or considerable stream of water may at times be there intersected and brought into the reservoir; or, another case may happen, in which the adjoining valleys instead of being parallel to, proceed directly from the reservoir valley, and yet feeders may be let out, so as to collect great quantities of rain and spring water, from the sides of the hills that slope towards the adjoining valleys, and through which it would otherwise escape. Both these methods we saw successfully practised about the year 1796, for increasing the supply to the new water-meadows which the late *Duke of Bedford* had directed his agent to construct near Woburn. A parallel valley, which crosses the turnpike road at about $4\frac{3}{4}$ miles from London, has its stream of water diverted at that point, and through a short tunnel into the Woburn vale, which it otherwise would not have reached for a mile or more, and at a much lower level. From the lowest point in the ridge of high land that separates the Woburn vale from one that proceeds through Potgrave parish towards Leighton, a trench or feeder was begun, and carried for a mile or more along the side of the hill in Potgrave, by which the rain water of 3 or 400 acres of land was brought into a reservoir in a branch of the Woburn vale, to be reserved for use.

The engineer, who has well considered and ascertained all the circumstances of the vales in or near to which his reservoir is to be constructed, will be able, by help of a number of levels, carried round to where the surface of the water will extend at every 5, 10, 15, 20, &c. feet in depth, or oftener, if the nature of the ground requires it, to calculate to what height the head of the intended reservoir must be embanked to retain all the water that his valleys can supply, between the times that it is fed by rains and springs, and required to be let off to the canal or mills, or such quantity only as it may be necessary so to retain, according to the principles before laid down.

The necessary height of the head or embankment for a reservoir being determined, the next step will be to examine minutely the nature of the strata and soil that are to be covered with water, and whether the whole or any part of the same is so porous as to require lining with puddle, as also the nature of the stuff which is to be used in forming the head or bank, as thereon will depend, in a great measure, the degree of slope which the banks ought to have; $1\frac{1}{2}$ to 2 feet base to one in height seems the usual slope; but if the soil should prove a slippery clay, as at the Aldenham reservoir, belonging to the *Grand Junction* canal, a greater slope should be given, as well as the precaution taken, of putting in frequent layers of sand or coarse gravel, to lessen the tendency of such soil to slip. If the reservoir will require bottom lining, yet still it will not sometimes be right to trust to lining for the head of the reservoir, but to carry up a puddle-ditch in the centre of the head, because if the inside of the head should happen to slip, the lining would be broken and disturbed. The slopes being settled, it will be right to make a cross section of the valley at the place of the centre of the head, as A C B (*Plate I. Canals, fig. 16.*) and to determine by levelling, and mark out the places of, as many perpendicular or equidistant ordinates a, b, c, &c. as the width of the head and the nature of the sides of the hills A C and

C B may require; we are next to consider, that the section of the intended bank at every one of the points *a, b, c, &c.* will be nearly triangular, as D G F, *fig. 17.* (except wanting a small triangle G H I at top) K E being equal to the ordinate *a, b, c, &c.* in every case; the base D F, or width of the head at the different places, varying according to the height K E, and according to the inclination or fall of the ground D F, compared with the horizontal lines F I, and I H. A theorem for E D and E F will readily be obtained with the above data, and these distances being calculated and laid off on the ground, so many points for the bottom of the slopes will be determined, and a careful workman will find no difficulty, by pegging down his line and holding his gauging-tool in the inclining position H D and I F, (as before mentioned respecting marking out the canal) to mark out a lock-spit, as a boundary or base for the intended embankment.

If the several triangular sections D G F are taken near enough to each other, A *a. ab, bc, &c.* and are carefully calculated (for which purpose in very large works, tables framed from the theorem will be found the readiest way), by deducting a triangular prism, whose base is H G I, and length A B, *figs. 16 and 17,* the solid contents of the required bank will be very exactly obtained; and the most eligible spots for obtaining that quantity of stuff, as near as may be, without endangering the slipping or stability of the bank, may be marked out; and the work will then be in a state to be let to the contractors who are to execute it. But before this is begun, it will be necessary to provide for the escape of the surplus water when the reservoir shall be full, as also for letting out the water for use; for these purposes an arch of brick-work, or of stone, may be begun at the lower limit of the bank in the lowest ground or brook course, as at D, in *fig. 18,* and continuing the same on a level to a point M, some distance within the head D H I E of the reservoir; D' L' being the lowest ground or longitudinal section of the valley. This arch should be high enough for a plank to be supported and fixed on irons or bearers across it, about a foot from its bottom, on which a man can conveniently walk along; and, for this purpose, the arch had better be made elliptical, or higher than it is wide; a secure iron gate should also be provided, to be kept locked at a few yards into the arch from D, for excluding improper persons. At the termination of the level arch at M, there should be a circular well of 6 or 8 feet diameter more or less, according to the greatness of the floods that may be expected, to be sunk 6 or 7 feet deeper than the arch D M; its bottom should be formed either of one very large flat stone, or of a few well jointed ones laid on a course of puddle, and on this the lining of the well should be begun, with bricks of the very best quality, well keyed up and embedded in cement; and having a course of puddle of 9 inches or a foot thick, worked all round behind them, allowing the same to set as the work advances in height; this well, and the arch D M, are to be securely groined into each other at M; near to this groin, or within reach of a man standing on the end of the plank above mentioned, which should not advance quite up to the well, should be a large brass cock worked into the walling; the mouth of this cock should be turned down, so as to discharge its stream of water exactly in the direction for the centre of the bottom of the well; and from the cock should proceed a large pipe of lead or cast iron behind the wall of the well at some distance, for which purpose it will require a considerable bend, and this pipe should proceed, soundly embedded in good puddle, towards a convenient place as S, in the bottom of the reservoir, where it should terminate under a large and stout box full of

holes, or a fine grating, to prevent the entrance of fish or any thing that might choke the pipe or cock. In constructing the arch before mentioned, after it has proceeded from D as far as the intended puddle-ditch *cd*; the puddle-ditch should be dug out for some distance on each side across the arch; the same should be continued down to water-tight stuff, or at least for some depth into other matter, if unfortunately such is not within reach; and, when the puddle is carried up and set, as also a course of puddle in the bottom of the arch course *dM*, which should have been dug deeper for such purpose; the bottom of the remainder *dM* of the arch should be carefully laid on the puddle, and a centering for the arch is to be laid on the same and firmly secured down; this precaution being necessary to prevent the semifluid puddle that is to be applied successively without the arch, as it is carried up, from floating or burying up the centering along with the lower part of the arch. The work is thus to proceed until the part of the arch *dM* is completed, and inclosed completely in a case of good puddle, thoroughly and completely joined at one end into the puddle-ditch *aefb*, and into the puddle that surrounds the well N M at the other. When the well-lining has been carried up to M, it will be necessary to increase the thickness of the puddle-wall round it, to three feet or more, taking care that the extra width is firmly bedded upon undisturbed and solid earth. The well is intended to be carried up in the same manner, surrounded by puddle, and by a conical embankment of earth O P Q R, to within two feet of the height of the bank H I, leaving a channel of several yards wide, and of considerable depth, I O P, between it and the bank or head D H I E. It will be necessary for the engineer to calculate and mark out the base of this conical embankment upon the ground, with allowance for ample slopes to prevent slipping or its washing down by the waves: it will also be proper, for ensuring stability to the work, to reduce the whole of the top of the work to one level as K L, as soon as can be, by successive layers of stuff thereon, and of puddle in the ditch *aefb*, and round the well N M: and, if the bottom of the reservoir will require lining, owing to the porosity of the soil; it will be right, after levelling and treading the part *b R* perfectly, to cover the same with 3 or 4 courses or linings of puddle, joining the same perfectly with the puddle-ditch, and the puddle round the well, to which courses of puddle the bottom lining is afterwards to be carefully joined; and after this is properly set, the remainder of the bank L H I E, and of the cone O P Q R, may be proceeded with, as we have before mentioned, when treating of the rearing of canal banks with puddle-ditches in them. The bank or head being completed to H I, and the well N M, and conical embankment O P Q R, being also carried up to the proper height, the well should then be coped with a layer of the best hewn stones cramped together, and the top reduced to a perfect level; and for security, it will be right to pave the surface of the top P Q, and for some distance down the sides of the conical embankment, with paving stones pretty well jointed, and set their longest way into the soil, filling their joints with mould, and sowing grass-seeds therein, to prevent the waves from afterwards loosening the stones or wearing the bank; this conical bank is for enabling the water to fall into the well on all sides; if the well was made in a corner of the reservoir, much digging would be required, both for the arch or pipe to let out the water, and for the discharging arch D M.

We have been thus particular in describing the circular weir or well-fall above recommended, from having seen the beneficial effects of one, in the reservoir for Worsley mills

near the duke of *Bridgewater's* canal; and the mischief that is sometimes done to the banks of a reservoir and the adjoining lands, by letting off the flood-waters by common weirs or tumbling bays at the corners of the reservoir, and suffering it to find or rather tear its own way down into the valley. Reservoirs constructed on the above principles would be secure almost from accident, however high the embankment, or sudden and copious the floods, if the well is but made sufficiently large, and deep of water at the bottom, to receive the shock of the descending column of water. If the floods are so considerable as to bring down timber and other large floating matters, it will be necessary to fix a strong grating or circle of bars round the top edge of the well bank *PQ*. It will sometimes happen, that a reservoir is over or near to the navigable tunnel of a canal, and might be let down into the same by a pipe and cock as at *Ripley* on the *Cromford*, and near *Braunton* on the *Grand Junction*. It will be proper, that the core or plug of the cock to a reservoir should be turned by an endless screw, or by toothed wheels, so that considerable power and nicety in the adjustment of the stream let out, by the turning of the cock, may be attained; and a regitler should be provided of the number of turns, and fractions of a turn, that is given to the winch or handle in any case. It will be proper to flanch on a small pipe to the large one, and connect the same with an inverted glass syphon filled with mercury, in the arch near the well, so that by turning a cock, the height of the mercury should indicate on a scale attached, what depth of water there is in the reservoir above, or how much it wants of being full at the time. A series of accurate experiments should be made, by gauging the stream of water at *D*, or at the first convenient place below it, which the cock discharges per hour or day, when the water is at different heights in the reservoir, and with different turns of the cock-geer; these should all be repeated, and sufficiently numerous, to enable the engineer by interpolation, to fill up and form a table, (that the committee ought carefully to preserve copies of) by which at any given height of mercury, the cock can readily be set to discharge any number of locks full of water that may be required per day. No great difficulty would attend the forming of a gauge-puddle, instead of, or by the side of the brass cock that should regulate itself, and discharge any regular and constant quantity of water that the reservoir could supply: see *Leybourn's Repository*, 8vo. question 81, p. 165. It will be right also for the engineer and committee, to have tables for readily shewing the quantity of water that every reservoir contains, at each foot or shorter portion of its depth, indicated by the mercury in the syphon, or by a graduated gauge-post fixed up in any part; for forming a table of this sort, where a complete survey had not been made or preserved at first, the time of a hard frost should be chosen, and a sufficient number of holes at equal distances, in a great number of parallel or equidistant lines, should be bored or cut through the ice sufficiently large to let down a plummet to sound the depth, and if this is done with care when the reservoir is full or nearly so, a most correct table of its content at different depths, can be thus obtained by calculation. Some of the considerable reservoirs that have been constructed for canals are, at *Aldenham*, *Daventry*, and *Wilstone* on the *Grand Junction*; *Kilsyth* on the *Forth and Clyde*; *Branstone*, and *Denton* on the *Grantham*; *Ripley* on the *Cromford*; *Amsworth* on the *Nottingham*; *Littleborough* on the *Rochdale*; *Mariden* on the *Huddersfield*; *Oxendon* on *Leicestershire and Northamptonshire Union*; in *Rudyard* vale near *Leek*, for supplying the *Caldon* branch of the *Trent and Mersey* canal, which covers 160 acres, has its head 30 feet high,

and the water in general very deep. *St. Ferniol* reservoir, constructed about the year 1673, on the canal of *Languedoc* in the south of France, occupies a space of 595 acres, its banks are walled round with free stone, and its waters let out when wanted, by a large pipe and cock.

In constructing Feeders or channels to convey water to a canal from springs, brooks, or reservoirs above its level, the same care must be taken to examine the nature of the soil in every part, and to apply a lining of puddle, as have before been mentioned respecting the line of a canal, wherever porous stuff is to be cut through. Where there are a great number of undulations in the ground, through which a feeder is to be conducted, that would occasion it to be very crooked and much impede the cultivation of the land, it will be proper, in many instances, especially if the land be valuable, to cover over the feeder in a culvert or small arch of bricks, of 18 inches or 2 feet diameter, or larger if the supply shall at any time require the same: in very porous soils, these culverts, inclosed in puddle, will be the most effectual way of preserving and conducting small streams of water, and no land will thus be lost to cultivation. In some places, feeders will require considerable embankments and aqueducts, to cross valleys and streams of water, and preserve their level, or gradual and small fall; and in many of such cases it will be cheaper and better to use cast iron-pipes well jointed and flanchied, and laid within the ground, down one side or bank of the vale to be passed, and up the other, securing each end carefully with a strong box full of holes, or a fine grating to keep extraneous matters out of the pipe. In the case of smaller feeders, particularly those temporary ones, which are required to supply water to puddle with, and to fill the bottom of the canal for the temporary use of dirt-boats while making it, as before mentioned, elm-pipes in short lengths, in which the most crooked arms of large trees will come into use, may be advantageously used in crossing hollow roads, or other sudden ravines, if the same be jointed by short hollow double cones of cast iron as recommended by Mr. *Hornblower*: see *Repository*, vol. x. p. 25. It has often happened, where reservoirs are situate at some distance above a canal, and a brook-course led from the reservoir to the canal, that the water was left to take its ancient course on being let out of the reservoir; an expert engineer will, however, carefully examine all such feeders, for thus they ought to be considered, and fill up all deep holes, and lower the shallows in the brook-course, so as to reduce the channel nearly to a uniform width and depth; and very accurate gauges of the water ought to be made at different seasons of the year, of the quantity issuing out of the reservoir arch, and the quantity received into the canal; if these differ materially, intermediate and comparative gauges should be made of the stream, until the faulty or leaky ground is discovered, probably some stratum of sand or open-jointed rock; over which the brook-course or feeder ought to be carefully lined with puddle; and, if puddling-stuff be scarce, the soil very porous, and the brook-course very crooked, it may be the most effectual way, as well as the cheapest in the end, to pass such leaky ground by a small culvert, inclosed in puddle under ground, by the side of the brook-course, as straight as the course of the valley will admit. Except in situations, where mills in the vicinity of an intended canal are much in want of water, or their owners or others disposed to thwart the scheme, it has been usual to allow the company to search for, and divert to their use all springs of water, within certain limits on each side of their line; in the acts for the *Newcastle underline Junction*, the *Southampton and Salisbury*, and the upper part of the *Tamer Manure* canals, this limit is fixed at 1000 yards; in the *Aberdeen, Polbrook,*

Tamar Manure lower part, *Thames and Medway*, *Wilts and Berks*, and others, this is fixed at 2000 yards on each side of the line. In such cases, an accurate investigation and knowledge of the *Strata*, upon Mr. Smith's principles, will be of the most essential importance, in order to collect and retain springs that are above the summit level, or even in lower situations, where a local trade is to be provided for. It has been usual in some mining districts to require, that engines near an intended canal should lift their mine-water into such canal, or high enough to be conducted into it by a feeder, as on the *Birmingham and Fazeley* canal. It will be worth considering, on a summit, where water is scarce, whether a tunnel may not be more eligible than deep-cutting, on account of large springs which would be intercepted by the lower level of the former, when the deep-cutting must perhaps be in porous stuff, or perhaps in dry open rock. As the summit pounds or levels of most canals are in deep cutting, through a considerable portion of their lengths, it is often attended with but little additional expence, except in the case of tunnels, to make such summits pounds one or two feet deeper in water than usual, as on the *Derby*, *Cromford*, *Manchester Ashton and Oldham*, *Oxford*, and other canals, in order that such additional depth, being filled in winter-time or wet seasons, may act as a reservoir for drier ones; but it has not always been considered, that such deeper pounds, when filled 18 inches or 2 feet fuller than is necessary, occasion the necessity of letting off twice that extra depth of water, over the area of a lock, each time that a vessel passes the summit; by which, such reserve of water is in a great measure dissipated before the dry season for which it was intended arrives. We should recommend, either the use of reservoirs, so much above the summit level of the canal, that they could be emptied into the same, when the continuance of dry weather required it; or, if such deeper summit pounds be made, on account of their considerable length for holding water, that a lock capable of penning 18 inches or 2 feet, and of shutting very tight, should in such case be built, near each end of the summit, to be used as long as the summit water is higher than usual, but which might at other times be left open, when the water was level on each side of them. Before we quit the subject of supplying a canal with water, we beg to mention, that it may be worth the while of the engineer, where water is to be pumped up to supply the lockage, as we have before mentioned, to design and calculate the expence of wind-machines, capable of doing the required work, and of the probable expence of their repair; and to compare the same, with the cost of erection, expence in fuel, attendance and repairs, of well constructed steam-engines to do the same work.

On the *erection of Aqueducts* for conveying a canal over any very deep and wide valley, or over a large or navigable river, we beg to mention, that a most secure foundation must be sought for, by sinking, or obtained by piling, for the piers of an aqueduct-bridge, and that the arches ought, in every case, to be arches of *equilibrium*, because the least settling in brick or stone bridges, by letting through the water, may prove of the most fatal consequence. That the plan of an aqueduct-bridge should be curving inwards, that is, the ends should be wider than the middle, the walls should also not be upright, but buttering or diminishing upwards without, to give greater strength and stability to the whole; the materials, if of stone or brick, and the cement, should be of the very best quality, and the work executed in the summer season only. In *Plate II. Canals*, figs. 19, 20, and 21, we have given a plan, section, and elevation of an aqueduct-

bridge, proper for crossing a considerable river, where, in *fig. 19*, A is the river, B the canal, C the towing-path, and D D the wing-walls, for keeping up the embankments at each end of the bridge: in *fig. 20*, C is the towing path, and a a a lining of puddle to secure the canal B from leaking. Care should be taken that all the joints of brick or stone are worked as close as possible in an aqueduct-bridge, and thoroughly filled with cement; the slopes within side, and the bottom for the canal, should be made rough, that the puddle may the better adhere to them, and that the puddle may not slip, owing to the steepness of the sides, which must be more so than in other parts of the canal, to avoid unnecessary expence of masonry or brick-work in the width of the bridge. The lining as above is, however, liable to be soon cut away by the barges. Since the year 1795, a new kind of aqueducts has been introduced into this country, composed partly of cast-iron, which promises the greatest advantages, except, perhaps, where free-stone of an excellent and durable quality is found upon or very near to the spot, or where the same is very distant from any iron mines, or existing navigations that connect with such. In the year 1797, Mr. *Thomas Telford*, the engineer, wrote an account of the inland navigation of the county of Salop, which has since been printed in J. Plymley's Report to the Board of Agriculture, on the Agriculture of Shropshire, and we beg to extract therefrom what he says on this subject when speaking of the *Shrewsbury* canal, p. 299, as follows: "This canal passes over the valley of Tern, at Long, for a distance of 62 yards, upon an aqueduct made all of cast iron, excepting only the nuts and screws, which are of wrought iron; and I believe this to be the first aqueduct for the purposes of a navigable canal which has ever been composed with this metal. It has completely answered the intention, although it was foretold by some, that the effects of the different degrees of heat and cold would be such as to cause expansion and contraction of the metal, which not being equal to extend or draw back the whole mass of the aqueduct, would operate upon the separate plates of iron so as to tear off the flanches which connect the plates lengthwise, and break the joints. Others said, that the expansion of freezing water would burst the sides, and so break off the flanches which connect the sides with the bottom plates: but after the trial of a summer heat, and the very severe frost of the winter of 1796, no visible alteration has taken place, and no water passes through any of the side or bottom joints. After the frost had continued very severe for three or four days, and the water had not been drawn off (although there are means of doing so), but it had stood in the aqueduct above the height of two feet six inches, the ice had then frozen to the thickness of an inch and a half, but instead of having forced out the sides, it was melted away from them, and quite loose upon the surface of the water. The idea of having this aqueduct made of cast iron was first suggested and recommended by *Thomas Eyton* esq. then chairman of the committee: after due consideration, it was approved by the committee, and the principles of construction, and the manner in which it should be executed were referred to Mr. *William Reynolds*, and the writer of this article, (Mr. *Telford*) who, after several consultations, and forming and considering various plans, at last determined upon that which is represented by the annexed engraving, (*Plate III. Canals*, fig. 22.)

"The castings for the aqueduct were done at Ketley, and were removed to Long, a distance of five miles, partly by land and partly by water-carriage. This aqueduct was proposed in consequence of the great floods which happened in the beginning of the year 1795, and it was fixed up complete

in March 1796." Mr. *Robert Fulton*, an American engineer, who happened to be in this country at the time, seems to have availed himself of what was going on at Long aqueduct as above, and of the machinery of various kinds, in use upon the *Kelley* and *Shropshire* canals, and to have prepared drawings and models of a variety of such machinery, with many improvements of his own, and submitted the same to the examination of a committee of the Board of Agriculture, in March 1796. These have since been published in a handsome quarto volume, entitled, *A Treatise on the Improvement of Canal Navigation*, by *R. Fulton*, from which, p. 114, we beg to extract what he says on constructing aqueducts of cast-iron for a narrow canal as follows: "The buttments and piers being raised, it will only be necessary to extend two pieces of timber across the span; each to be braced back to the piers, and covered with plank to form a stage or scaffolding which will answer every purpose of centres necessary to works of stone. The iron-work, as in the section (*Plate III. Canals*, fig. 23 and 24.) may all be cast in open sand, and of the following dimensions: supposing the span 100 feet and the spring one-sixth of the span. First, three segments of a circle, each in three pieces, about 36 feet long, eight inches by four diameter, to be united, as at A. Second, three straight bars, to extend from one pier to the other, to be of the above diameters, may also be cast in three pieces, which bars are to extend along the top of the segments to the piers, and form a line parallel to the horizon; the bars and segments to be united by perpendicular stirrups like B, ten or fifteen feet distant from each other. The mortice in the lower end of the stirrup being thirteen inches long, will be sufficient to secure the segment, and leave room for a hole two inches square, through which a cross brace, C, is to pass, and fasten the segments at proper distances; the brace to have a mortice, cast on each side of the stirrup, in order to tighten the work by wedges. On the top of the stirrup, the square hole to receive the cross brace may be beneath the mortices, as in the figure; by which means the whole may be combined, and form an iron stage to support the troughs. The trough plates should be at least one inch thick, the side plates six feet broad, and as great a length as can conveniently be cast; which may be performed twelve feet, and perhaps more in length: the flange to be outside on these plates. The bottom plates may be six feet wide, thirteen feet long, seven feet plate, and four arms projecting, each three feet long, in order to support the horse-path and braces, as exhibited at D. Two of these plates laid across the stage, and screwed together, with a flange under, will compose a length equal to one of the side plates, which may either meet or break joint as is thought proper. The whole may, in this manner, be screwed together, on packing of wool and tar, and have the seams pitched like those of a ship. On the plates composing one side of the trough, small brackets, about three feet from the top, must be cast, as at E, in order to support the horse-path; perpendicular rails, eight feet long, being raised from the arms of the bottom plates, will support the outside of the horse-path, also the iron railing, as in the section. By this mode, two patterns will answer for the whole of the trough-plates, and but few will be required for the springs, rails, and spurs; while the saving in time and expence will be considerable; particularly where it is necessary to bring the stone by long land carriage; for the arches being dispensed with, and the piers not more than one third of the dimensions necessary to an aqueduct of stone, will most materially reduce the quantity of masonry." "In aqueducts of stone, one of the great difficulties is to line and puddle so tight as to prevent the water penetrating into and injuring the masonry; but in one of

iron, should a leak take place it will instantly appear; and on shutting the stop-gates at each end, and discharging the water, it may be stopped in a few hours, if not minutes: this circumstance in aqueducts is, perhaps, one of the greatest preservatives; they are consequently less liable to injury, and only subject to the corroding tooth of time."

Since the above period, a most stupendous work of this kind has been undertaken by Mr. *Jessop*, on the *Ellesmere* canal, and is now nearly or quite completed, for crossing the *Dee* river at *Pontcysyltee*, about 20 miles S.W. of *Chester*; where nineteen massive conical pillars of stone, at fifty-two feet from each other, the middlemost of which is no less than 126 feet in height, support between the top of every pair, a number of elliptical cast-iron ribs, which by means of uprights and horizontal bars, support a cast-iron aqueduct about 329 yards long, 20 feet wide, and six in depth, composed of massive sheets of cast-iron, cemented and riveted together, having on its south side an iron platform and railing for the towing-path. In May 1796 Mr. *James Jordan* took out a patent for suspending aqueducts from ribs of cast-iron above them, in the same manner as his suspended iron bridges. See *Repertory*, vol. vi. p. 230. Among the most considerable aqueducts of stone or brick are those at *Lancaster* on the *Lancaster* canal, for a description of which see our article *BRIDGE*. At *Kirkintolluch* and at *Kelvin* on the *Forth and Clyde*, *Chirk* on the *Ellesmere*, *Marple* on the *Manchester*, *Aldon* and *Oldham*, *Monk-bridge* on the *Trent and Mersey*, *Whaley-bridge* on the *Peak Forest*, *Avoncliff* and *Dundas* on the *Kennet and Avon*, &c. while at *Burton* on *Bridgewater's*, a navigable river is passed, and near *Wigan* on the *Leeds and Liverpool*, another canal (the *Lancaster*) is passed upon aqueducts. It was thought a bold and visionary scheme by many, which Mr. *James Brindley* proposed, of crossing the *Mersey* river at *Runcorn Gap*, by an aqueduct bridge, but no doubt he could have accomplished it.

The making of *Embankments* appears to have been long practised in *China*, where we read of parts of their canals of 200 feet wide, that are embanked 20 feet high, for great lengths together; the rivers through the fens of *Cambridge* and *Lincolnshire* in this country, have also been long confined thus, by artificial banks. Most of the aqueducts of which we have been speaking above, have less or greater lengths of solid mounds or embankments for forming the canal upon, to the proper height, and for joining them to the aqueduct bridges; all the observations and remarks which we have made, respecting the setting out and ascertaining the dimensions of the head of a reservoir, will apply to embankments; except that a prism whose base is the figure G H L M N O I, *Plate IV. of Canals*, fig. 25, and length A B, fig. 16. *Plate I.* is to be deducted from the triangular embankment D G F, first to be calculated, instead of the triangular prism G H I. The angle of the slopes ought to be determined by the result of similar inquiries, and the same precautions used to prevent slips, in soils that are so disposed, as were mentioned respecting reservoir heads; it will generally be a safer way to carry up a puddle-ditch in each bank of the canal, as *a e, b f*, fig. 25, than to trust only to lining of the canal L M N O. In every considerable embankment there will be required one or more arches to convey a brook or river under the canal, and, perhaps, others for roads to pass through; such arches should always have an inverted arch turned below them, deep enough for the bottom of the brook, and below the roads, and the arch itself should be one of *equilibration*. To avoid making a very large arch for a brook or small river, it is usual to make a road or communication arch near it, with

its bottom well paved, and no higher than the surface of the meadows, which will serve to vent the sudden flood in rainy seasons.

Great care should be taken to slope off and finish the ends of arches under an embankment, agreeable to the slopes or sides of the banks thereof; by which the banks are prevented from mouldering down into the brook or road-way, and awkward projections in the slopes of the banks are avoided: at the entrance or upper side of a water-arch, or of road-arches that will occasionally become such, return or wing-walls of brick-work or stone should be made, for some distance along the bottom of the slope of the embankment, and the sharp corners of the entrance of the arch should be a little rounded off, to prevent the rapidity of sudden floods from wearing or injuring the bank. It is to be observed, in conducting a canal along the side of a steep and high hill, as *Plate I. fig. 3*, that after a certain degree of steepness of the ground $A'P'$, it will not be possible to cut the canal, upon the principle that the excavation $EFGIKP$ shall just form the bank $ABCE$, but such banks will often require stuff to be provided from other places, and such are indeed cases of embankment: and here it may be proper to advise, that new banks, as $ABCE$, ought not to be placed on very steep ground, as AE , without considerable care in first forming it into levels like steps, to prevent the slipping of the new part, as happened near Bradford on the *Kennet and Avon* canal, after all the care that was taken, and great lengths of the canal banks slid down into the *Avon* river below, the making of which good again cost, we were told, near 1000*l*. Among the considerable embankments that have been made for canals, are those at Bollin and Stretford on *Bridgewater's*, and Wolverton, Weedon, and Bugbrook on the *Grand Junction*, &c. but the greatest extent of high embankment known, is that in the valley of the Boyne, in the *Grand* canal of Ireland; and the highest bank in the world is also to be found on the same canal in the valley of the River Rye; it is above 90 feet high. We are told, that Mr. *James Brindley* used a kind of caisson of planks, in forming his great embankments, in which dirt boats were used, to bring stuff from the higher ground, that had been cut through.

We have next to speak of *Safety-gates*, *Stop-gates*, and *Stop-planks*, which are different contrivances for stopping the water of a canal in case the banks are failing in any part, or that any part wants emptying to repair the works. Advantage is generally taken of the walls under the bridges, for constructing these contrivances, where the same happen in the proper places; otherwise the canal must be contracted by upright walls, the same as is done at the bridges on purpose for them. For explaining the nature of safety-gates, we must have recourse to *fig. 26*, where AB is supposed to represent the top of the wall, or height of the towing-path under a bridge, CD the surface of the water, and QS the bottom of the canal; $EFGH$ is a pier of hewn stones, or a piece of sound oak timber let into the wall, its face being flush therewith; IEG and HFK are recesses about two inches deep in the wall; similar provision is made in the opposite wall, for receiving doors or gates LM and NO across the canal, turning on centres or hollow-quoins at M and N : each gate is so balanced by a counter weight, that they rest always in the position represented: and they are intended to operate thus, suppose, owing to the sudden breaking of a bank, the water in the canal should acquire a current from Q towards S , the stream would pass under the gate at PL , to facilitate which, the corner of the floor at P is sloped off; the gate would be turned up into the position ME , and the canal would be thereby closed up. The like would happen by the other gate NO , in case of a current the con-

trary way. Safety-gates should be placed at proper distances on every long level or pond of water, especially if the same is much embanked; both to prevent the loss of so much water, in case of a bank breaking, and the mischief that the same would do to the lands, mills, &c. below the breach. We read of a new bank breaking on the *Warwick and Birmingham* canal, and destroying a gentleman's park-walls; and in the year 1783 so great a breach suddenly happened on *Bridgewater's* canal, near London bridge on the Chester road, that three barges were carried through the same a great way out into the fields. A single safety-gate ought to be placed at the end of every long embankment, to stop the water in case of a breach happening in its banks. *Stop-gates* are similar in their construction to the safety-gates above described, except that the gate lies flat on the bottom of the canal instead of being balanced, and has a chain by which it can be hauled up, whenever occasion may require the canal to be stopped. *Stop-planks* are a simple, though not so expeditious a provision for stopping a canal as the last; a groove is provided in the two opposite walls under a bridge, or in a narrow and walled place, and a sufficient number of well jointed planks are provided, to be dropped into the groove whenever the water is required to be stopped, and hence these are often called drop-planks. In very large works like the *London docks*, a barge or vessel is built in the place, whose head and stern posts exactly fit into a groove as above, and the vessel can be floated into and out of its place, or sunk therein as occasion may require. The engineer will also have to make provision, while the canal is digging, for *stop-bars* at the several intended toll-houses, or other places where it may be necessary to stop barges in the night, or in case of any dispute about their lading: these bars are composed of a large baulk of fir timber floating on the water; and a small arch capable of containing such a floating beam of the proper length is provided under the bank, so that when the trade on the canal is required to be stopped, the toll-clerk has only to draw out the beam by means of a cord attached to it, until its end enters a recess in the opposite wall, and then to lock the beam fast.

We shall next describe the *Waste-gates*, *Trunks*, *Tumbling-bays*, or *Weirs*, that must be provided, for letting off the superfluous water of a canal in wet times, for keeping the water to one certain height, or drawing it off in case any repairs may be wanting. *Waste-gates* are sluices of the common construction in the side of a canal, where any considerable quantity of water is required to be let out, and are to be drawn up, either by a rack and pinion, a chain and roller, or a number of holes for a crow-bar, as circumstances may render most eligible: where lesser quantities of water are to be let out, or for emptying certain lengths of the canal between the stop-gates or planks, when occasion may require; *trunks* formed of oak or elm planks, well jointed, should be laid into the bank, at the bottom of the canal, and carefully inclosed in puddle, with a valve or shuttle that will shut very tight, and can be readily drawn when the water is required to be let off: we beg to recommend, wherever wooden trunks are used for any such purpose, that they should be sunk so low, or the mouth where they discharge should be made up, so that the trunk may always remain quite full of water, and the air be at all times excluded; in which situation wood will last much longer than if wet and dry alternately.

In the choice of situations for *weirs*, to discharge the surplus water of a canal, care must be taken not to let off any considerable quantity at any time, but into a brook-course or bottom of a vale, that is crossed or proceeds up to the canal, and has ditches through which the water can escape,

without tearing or doing injury to the land adjoining. The most frequent *tumbling-bays* or *weirs* to discharge water from canals are composed of strong walls of brick or masonry, as *gc*, Plate IV, *Canals*, fig. 27, whose top *g* is coped with hewn and well jointed stone, or with a stout sill of oak, the top of the same being just level with the top-water line *gDH*, or about one foot lower than the top-bank *DCIK*, *Ac* is a paving of large stones for the water to fall on, and escape at *A*, and *ABc* are wing-walls at the ends of the weir, to keep up the bank and confine the water. These weirs are generally on the towing-path side, on which a low plank bridge, as *Cl*, is supported over it, called a weir-bridge. When these weirs are wanted of considerable length, the wall *gc* ought not to be straight but on a circular plan, curving inwards in the middle, by which it will be better able to support the lateral pressure of the bank behind it; a puddle ditch should be carried up immediately behind the wall, allowing the courses of puddle to set thoroughly, before others are applied, that the great pressure of the semifluid puddle may not overset or disturb the wall; and the paving *AC* should be of large and well jointed stones, and if set upon a course of puddle it would be a further security against their washing up, which too often happens. We have seldom seen any considerable weirs or tumbling-bays of the above construction, but where it would have been better to have followed the example of Mr. *James Brindley*, on *Bridgewater's* canal, and have made a *circular-weir*, or well-fall, on the upper side of the canal; we have spoken of these when treating of the general improvement of a valley, as also in the making of reservoirs, but it may be proper here to refer to a section of such a well-fall in fig. 28, where *A'P'* is supposed to be the section of a vale crossing the canal *CFG I*; *AM* is an arch of brick-work, secured on its upper side at least, with a covering of puddle, and *MN* is a well, whose steining or lining of brick or stone is groined into the arch at *M*, having a well paved floor, three or four feet below *M*, according to the height *NM* that the water is to fall, and a coping of hewn stone, or a large curb of sound oak at its top. *IOPQR P'* is intended to represent the section of a side pond or wider place in the canal, from which the water may drop quietly into the well at *N* from all sides, and run off at *A*.

For letting a proper quantity of the surplus water of a canal forwards into the ponds below, a small weir is generally constructed in the walls at the head of each lock, which lets the water down into the paddle-holes, or crooked arches that convey the water for filling the locks, and hence such are called *paddle-weirs* or *lock-weirs*. The upper gates or doors of the locks are often boarded no higher than the top-water line, and therefore act as weirs for discharging surplus water into the lock; and gates of this sort are called *flood-gates*.

On the *construction of Culverts*, or drains under a canal for conveying away water from the upper to the lower side of the canal, it remains for us to say, that they should be carefully apportioned in size to the stream that is to pass through them in floods, and should be constructed of sound brick or stone work, and inclosed, or at least well covered on their upper side with puddle. Many engineers have used wooden trunks for this purpose, but except wood be in great plenty, and of the best quality, and good bricks or stone very difficult to be procured, it is not advisable to use perishable materials in such situations. If the ground be moory or bad; and a culvert must lie pretty near to the bottom of the canal, and have but a slight covering, it may be proper, in some situations, to use cast-iron cylinders flanchied together, as was done under or near the *Staffordshire and Worcester* canal;

and such may be made cheaper and easier of carriage, by being in two or three segments longitudinally, to be flanchied together before they are laid down; and in such situations, perhaps leaden rivets might be cheaper and be more durable than wrought iron ones, or nuts and screws. If bricks are to be used in culverts, over soft and moory ground, or quick-sands, a cradle composed of ribs of wood and boards or rails, such as are used for centering, should be prepared, suitable to the outer curve of the intended culvert, and such a cradle should be carefully embedded, in the proper place to receive the backs of the lower segments of the culvert: for want of such precaution many a culvert has sunk partially, perhaps owing to the springs excavating the land or filth from below, and has been broken, to the great injury of the canal. Culverts are of so much importance, that too much care can hardly be taken to make them solid and secure, and to cover them effectually with puddle: another hint we would here give, respecting the choice of places for the culverts; they should never, if possible to avoid it, be made exactly in an old brook-course, ditch, or slough, but in the nearest sound ground; and where often they can be got down to the proper depth, without any trouble from water, or at least the same can be easily pumped out; and the stream need not be admitted to the work, until the old brook or slough is required to be filled up. In this way it often will happen, that culverts may remain during the winter following their construction, completely excluded from the frost, and therefore may be done later in the year, by filling in the stuff upon them and at their ends, and the mortar be completely set before the new channel at the ends for conducting the water through them need to be cut. And we beg to remark, that by an attention to this circumstance in making new arches under roads, and keeping the bottom of the arch much lower than is generally done, or indeed practicable in the old channel or slough, half or two-thirds of the whole expence will generally be saved; for a deep and new channel being cut to the new arch; with scouring out the brook-course for some distance below, old ford-places, if the descent to them be easy and convenient, will not require immediately to be filled up or altered; but during any extraordinary flood, the same, if composed of gravel and hard stuff, may act the part of a weir for a short time, in carrying off the water, without injury to the road or material inconvenience to the passengers. It will sometimes happen, that a small stream of water is required to pass under the canal, in places where it is not embanked; in such cases a crooked or *broken-backed culvert* is to be made, as *m o n*, fig. 29, for passing the water from *m* to *n* under the canal *CFG I*; this will require puddling as before described, and a strong box full of holes, or grating, should be fixed over each of its ends, as well as pits or holes be made at the upper end, deeper than the mouth of the culvert, to receive and detain the sand and gravel which the stream may bring down in hasty rains, otherwise these, or the stones that mischievous boys might throw into it, would in time choke it up between *o* and *o*.

The *construction of Tunnels*, or subterraneous arches, for drawing off or conveying of water, has been known from the earliest periods, as appears by the celebrated works of this kind between lake Copais in Boeotia and the sea; between the lakes formed by the inundations of the Nile in Egypt and the Mediterranean; as also by the courses of the Roman aqueducts, many of which were tunnelled through hills of great extent. In the mining districts of this country, we have long had levels or audits of considerable extent to mines; in the neighbourhood of Matlock in Derbyshire, the *Helcar Sough* has been cut through the solid rock for nearly four

miles in length, for the purpose of draining the several lead mines in the vicinity; *Wirksworth Moor Sough*, of near three miles long, and *Cromford Sough*, of two miles in length, with many others of less note, are also to be found at great depths in that neighbourhood. The first tunnel that we read of, as constructed for the purpose of navigation, was by *M. Riquet*, near Beziers on the *Languedoc* canal, in France; and the first in this country, was the entrance made by *James Brindley* to the duke of *Bridgewater's* coal-mines at *Worsley* near *Manchester*; while the first of our tunnels undertaken for the purposes of general trade, or as a thoroughfare, was by the same engineer at *Harecastle* on the *Trent and Mersey* canal. It is very essential to the convenience as well as the beauty of a tunnel, that the arch thereof should be quite straight, and exactly level; considerable care will therefore be necessary in obtaining an exact section, by levelling, of the hill that is to be perforated, when a line in the exact vertical plane of the tunnel is fixed and staked out over the hill; in doing which, it will be right to choose the narrowest place that the hill presents at the proposed level, and where also the hill rises rather boldly from such level; otherwise an expensive and troublesome length of deep-cutting would be necessary, or of the tunnel that must be dug out from above and then covered up again, before a sufficient depth of stuff over head would be come at, to admit of working under ground; it will also be of consequence, when determining the exact line for a tunnel, to avoid having the deep-cutting and entrances in alluvial or disturbed and slippery soils, but, if possible, to enter at once upon the solid and undisturbed strata of which the hill is composed.

It will but very rarely happen, and that only on short tunnels, made for the purpose of preserving the level of a canal, that the workings will not be in soil more or less full of springs of water; therefore one of the first operations, after the line and level of a tunnel is finally determined on, is to search by levelling for a place in the nearest vale or brook that is some feet below the proposed level of the bottom of the tunnel; this must be more or less, according as the intended tunnel is of greater or less length; and from this point a large ditch must be opened, with a very small rise towards the end of the tunnel, as far as is practicable, and then a heading or sough must be begun, just large enough for men who are used to such business to work in, and to line it securely with bricks as they proceed, but leaving proper openings in the joints for the springs to collect freely from all sides into their heading. Some persons have supported their headings with boards and props of wood, instead of arching them; but which practice we cannot recommend: all such works ought to be durably constructed, or should any accident or circumstances, as the want of money, &c. delay the completion of the work for some years, all this tedious and expensive work will perhaps require doing again; it ought also to be considered, that after some years or ages have elapsed, the tunnel may want repairs or alterations, and that the same headings may be again opened and used, to lay it dry in a short time, if durably constructed; which may be of the most material consequence in lessening the period of interruption to the trade by such repairs or alterations. It will be necessary to begin a heading as above-mentioned on each side of the hill, and work them up towards each end of the tunnel, along the line of which it is to proceed from each end, rising gently as it advances towards the middle point, that the water may run freely off; the headings should be a few feet below the bottom of the working, that will be necessary for the inverted arch of the tunnel, and a few yards off on the side of it; and cross headings or soughs must, at stated distances, be run under the line of the tunnel, into which, openings can after-

wards be made to let off the water which collects in each separate working. If the soil be rather stiff, and the quantity of water in it not very considerable, one heading may suffice; but where porous stuff, with great quantities of water are interfectured, it will be necessary to branch off an additional heading, to proceed along the other side of the line, the more effectually to draw off the water; by which, perhaps, if the headings are done a sufficient length of time before the tunneling is begun, a quick-sand, or similar running of the stuff, may in several places be prevented. If in driving the headings, any fissures or cavities filled with sand or loose matters, are interfectured, and are found to bring a considerable quantity of water from one side of the line, it may be right to drive a cross heading for some distance into such porous stuff, for intercepting the water before it reaches the intended workings of the tunnel.

The next operation will be to set out a line very truly parallel to the line of the intended tunnel, and to mark thereon, at equal distances, about 150 yards apart, or oftener if great expedition in completing the tunnel is required, the place of the several tunnel pits, that are to be sunk for drawing up the stuff excavated from the tunnel, and letting down the centres, bricks, and other things wanted in the work; it will be well to contrive the line of the headings and tunnel-pits, so that they may coincide; and in great lengths of heading shafts or tunnel-pits may be sunk at intervals, to give air to the headings, and through which the stuff excavated therefrom may more readily be drawn up; and it may be advisable, in some instances, to set out a line on each side of the tunnel, for the tunnel-pits to be some on one side and some on the other of the tunnel, and that both may in places intersect the headings. If bricks or stones are not at hand when the tunnel-pits are begun, and wood is plenty, the shafts or tunnel-pits may be made square, and have their sides supported by boards and struts of wood; otherwise they should be made round, and lined or steined like a well as soon as they are done; if the soil should prove loose and full of water, it will be necessary to stein the shaft as soon as such soil is reached, and to work afterwards from underneath the curb, and let the steining sink, as is done in well sinking. Some tunnel pits have been made over the line of the tunnel, but such do not admit of being steined with safety, on account of the weight thereof, which would damage the crown of the tunnel, where they were groined into each other; and such of them as are left afterwards for air shafts, if the soil is wet, will let an unpleasant dripping of water down upon the goods or passengers in passing through the tunnel, as we once experienced in passing through *Braunston* tunnel on the *Grand Junction* canal. A common roll and winch will be sufficient for drawing up the stuff and water, and letting down bricks to stein with, unless the quantity of water is considerable; but it will be proper to erect a horse gin, or turn beam, such as are used at the shafts of coal-pits, for the cheaper and more expeditious drawing up the stuff and letting down of materials, when the workings have commenced. We have before recommended a line to be staked out exactly parallel to the line of the tunnel for the centres of the several tunnel-pits, and care should be taken that no gin, or other obstruction, be erected in this line, so that a fine line or string can at any time be stretched across the top of any of the tunnel-pits, and be adjusted without fear of mistake in the exact range of this line, or parallel to the intended tunnel. When a tunnel-pit is completed and steined, and a communication formed with the heading to keep the same clear of water; two points must be fixed in the steining near its bottom, by letting fall or suspending plumb-lines, at the time that there is no wind to disturb their verticality, and adjusting

another fine line between the two points on the steining below, so as to be exactly under and parallel to the line above and consequently so to the intended tunnel. The engineer should carefully repeat his levels and transfer the level of the bottom of the intended tunnel, or the surface of the water of the canal therein, and mark the same carefully in the steining of each tunnel-pit: and thus the workmen who are to undertake the work will be furnished with the direction, level, and distance of the tunnel they are to form under ground.

The work commences, by excavating a passage from the tunnel-pit into the line of the intended tunnel, and supporting the same properly with timber, or walls and an arch, as a passage into the work. A piece of the intended tunnel, a yard or more in length, according as the soil is found to stand, is then excavated, in the proper form, place, and level, ascertained from time to time by stretching a fine line between the marks, on the steining before-mentioned, and measuring therefrom, and using a common plummet-level for transferring the level from the level-mark on the steining before-mentioned; great numbers of ribs for centerings should be prepared in different segments, and in readiness to put together with nuts and screws, leaving as much room in the middle or centre as can conveniently be done, for the men to work and pass through after the same are put up; the parts of two of these ribs are then to be let down the tunnel-pit, and to be put together and fixed up in their proper place and distance asunder in the tunnel; short lengths of boards or laths are to be prepared and fixed on their outsides, as the turning of the arch proceeds; which, as well as every other part of this very difficult work, requires the utmost care and experience to make it found and substantial; when this first yard or less in length of the tunnel is turned and securely keyed up, the same is secured by ramming in clay, or proper stuff, so as to fill every cavity above or withoutside the brick-work. The workmen then begin at each end of the piece that is turned, one party working one way along the line of the tunnel, and another the contrary way, until another yard or other length of the tunnel is excavated, when other ribs are put up and fixed together, boarded, and the brick-work is turned round or behind, the same as before; the utmost care being taken to joint these courses evenly and securely into the former ones: the vacant space is then rammed up with earth, and a new excavation proceeded with at each end as before. The engineer ought frequently to renew his level-marks from fixed and good bench-marks on the ground, and to examine and adjust the ranging line, and also himself most carefully inspect each working of the tunnel, and examine, by stretching a fine line along its centre, and measuring and levelling to his ranging line in the tunnel-pit, to see that every part of the work is proceeding exactly in the same line, and so that when in process of time each adjacent working shall be joined, and the tunnel be completed, the whole may form one exact and truly straight arch. If the ground proves loose and bad for standing, it will be proper to continue the work, by different sets of men, without any intermission; and care should be taken that the work never is left, even for a night, without templets, or short pieces of plank, being put up to cover the roof, that is necessarily left open to admit the men's heads and arms, while they are turning and backing up their last length of work at the crown; and these templets should be securely shored up by spars or struts, to prevent the earth from settling or falling in, which has actually happened in some tunnels, owing to the neglect of this simple and necessary operation, so that a considerable length of the tunnel required to be dug out from the surface of the ground to repair the breach. When the tunnel and ends are completed, ditches are to be dug out, across the

headings, near the entrances of the tunnel, and a substantial puddle-ditch carried up, to effectually dam them up, and force the water that afterwards collects in them to rise up into the tunnel, through cross-headings to be left for that purpose.

The tunnel at Blisworth, on the *Grand Junction* canal being the latest that has been completed (Feb. 1805,) we have ascertained the following particulars relating to it, in order to give some idea of the present state and expences of tunnel making. The internal width of this tunnel is 16½ feet, the depth below the water-line to the inverted arch 7 feet, and the soffit or crown of the arch is 11 feet above the same line. The side-walls are the segments of a circle of 20 feet radius, the top arch of one of 8 feet radius. The side and top walls are 17 inches, or two bricks thick, and the bottom or inverted arch 13 inches, or 1½ brick thick; every fifth course of the top arch, and every eleventh of the side walls, is composed of two heading bricks, or wedge-like, one inch thick on the inside and three at the back; also, every fifth and eleventh course as above (but between the courses of heading bricks) are composed of bricks laid obliquely across the others, the front and back corners being cut off for that purpose in the making, for more effectually breaking the joints, of work obliged to be done in such short lengths. The mortar that was used, was composed of one bushel of Southam lime (*blue lias*) and three of good sand. Six inches under the water line, on each side of the tunnel, slide-rails of fir, 5 inches square, to keep the barges off the walls, are fixed by pieces of oak let into the wall below them; which rails project 9 inches from the wall, and have at every 9 feet, a chock of wood upon the rail, for the bargemen to set their pole against for shoving their barges along. And we were told that this tunnel was contracted for, at 15l. 13s. per yard run; the soil principally a hard blue clay, with two or three thin rocks in it. Sufficient headings had been executed several years before at the company's expence. The same contractors were paid 10½ d. per cubic yard for excavating the deep cutting at one end of this tunnel, and 11 d. per cubic yard for the other. The expence of driving the above headings were, we understood, from 36s. to 42s. 6d. per yard run. Nineteen tunnel-pits, some of them 60 feet deep, were sunk for the use of the above tunnel, which cost about 30s. per yard in depth including steining. In our inquiries respecting Braunston tunnel, on the same canal, we were told, that 320 yards of the same was drove in quick-sands, and that it cost 4800l. extra on that account. The Foulridge tunnel on the *Leeds and Liverpool* canal, of 1630 yards long, proved to be in such very loose and bad ground, that the whole of it, but about 700 yards, was obliged to be dug out from above; in some parts 30 yards wide at top, and near 20 deep, and immense works of timber were necessary to support and keep the banks apart, while the tunnel was turned, and the soil filled in again. Some part of this work, done about the year 1794, cost 24l. or more per yard run.

After a good length of the tunnel has been completed and well backed up, and been allowed some days or weeks for the earth to have settled regularly upon the brick-work, the centering may be removed, by loosening the screws and taking it to pieces, to be again put up and used further on in the same working. In tunnels upon high levels in porous soils, and in others sometimes near their ends, or in crossing any dry and porous stratum, it may be necessary to excavate the bottom a foot or 18 inches deeper than usual, and to fill the same up again with well wrought and stiffish puddle, and to turn the inverted arch, and as much of the sides as are below the water-level, upon the same, when set. Mr. William Chapman, page 52 to 54 of his *Observations, &c.* before

quoted, has given several directions for setting out tunnels, where coal-strata are intended to be intersected and worked thereby, as at Worley on *Bridge-water's*, and Harecastle on the *Trent and Mersey* canals. It will be a matter of some importance, for the engineer to attend to the removing of the top-soil from a sufficient space near each tunnel-pit, and to cause the same to be evenly covered, or the holes therein filled up, with the stuff that is drawn up and wheeled away from the tunnel-pits; and as fast as the different parts of the tunnel are completed, reserving stuff enough to fill up such tunnel-pits as are not to remain for air-shafts, to cause the top-soil to be returned upon such places, to avoid a heavy expence for spoil banks, besides putting the farmers and neighbourhood out of temper by seeing the apparent waste and devastation that such works make, when carelessly or negligently performed. The want of a towing path through a tunnel must be very apparent, to all such as have seen the tedious and barbarous process in use, of a man lying at length upon the gunnel of the barge, and pawing the walls with his feet; in narrow boats this is still more evident, where a plank is obliged to be laid across the barge for the men to lie down upon their backs, in order to be able to reach and paw the walls with their feet! The tunnel near Atcham on the *Shrewsbury* canal, though of 970 yards in length, has a towing-path through it; so has one at Newbold on the *Oxford* canal, and many other short ones in different places. In all short tunnels, and even in long ones, if the ground proves, on examination, sound and good for tunnelling, it certainly would be worth while to give the necessary width to the arch, to admit of this essential appendage.

Among the most considerable tunnels that we have, are those at Worley on *Bridge-water's* canal, 18 miles in length! Marsden on the *Huddersfield*, 5280 yards; Sapperton on the *Thames and Severn*, 4300 yards; Pensax on the *Leominster and Kington*, 3850 yards; Laplat on the *Dudley*, 3776 yards; Blisworth on the *Grand Junction*, 3080 yards; Ripley on the *Cronford*, 3000 yards; Dudley on the *Dudley*, 2926 yards; Harecastle on the *Trent and Mersey*, 2888 yards; Norwood on the *Chesterfield*, 2850 yards; West-Heath on the *Worcester and Birmingham*, 2700 yards; Morwellham on the *Tavistock*, 2500 yards; Oxenhall on the *Hereford and Gloucester*, 2192 yards; Braunston on the *Grand Junction*, 2045 yards, &c.

The longest tunnels that have been proposed, besides the above, were one of 5 miles on the once proposed extension of the *Manchester Bolton and Bury* to the Calder river; and one of $4\frac{1}{2}$ miles on the *Parismouth and Croydon*, through the chalk hills south of the latter place. The towns of Manchester, Kidderminster, and Southampton appear to be tunnelled under by the *Bridge-water's*, *Stafford and Worcester*, and *Southampton and Salisbury* canals respectively.

The executing of deep-cuttings appears to have been long familiar to the Chinese, since we read of some of their canals that are in places excavated 80 feet deep! and of others that are cut 20 feet deep for seven or eight miles in length! The setting out and determining upon the slopes of a deep-cutting of considerable depth and length, are objects deserving more of the engineer's attention, than has in too many instances been bestowed upon them: the first step, after the line and the level of the intended canal are determined upon, should be to examine minutely the soil in every part that is to be cut in, and to prove the same by the sinking of several shafts; if any of these, towards the centre of the hill, should be found in loose and porous soil full of water, while the ends of the intended cutting may appear to be in sound stuff; it will be worth while, in some such cases, to put down pumps and erect a temporary steam engine, to pump

up the water during the work, and to drive headings from such pump-shaft, on one or both sides of the intended cutting, and below its bottom, as has been before mentioned, preparatory to driving a tunnel. Should the whole of the cutting appear to be in loose alluvial stuff, full of water, and disposed to slip, or a part only of the ground at one end, as happened at the south end of the deep-cutting near Tring, on the *Grand Junction* canal, it certainly will be right to begin such part, by driving a heading up from a proper point below the intended cutting, and to give time for the springs to drain off before the cutting is begun, which may afterwards proceed in separate lengths at the same time, and with much greater certainty and dispatch, by the help of cross headings, to drain off the water, than is practicable without such precaution, unless expensive and very powerful pumps or machines are used in the works to clear them of water in different places; while the tendency to slip is much increased by such sudden and partial drawing off the water. Slips are among the most formidable accidents to which canal-works are liable, and can hardly be too much guarded against, by giving an extra slope to banks in such places, but particularly by driving headings behind such parts, some time before the workings are begun, in order that the springs may be intercepted, by which the most porous and loose stuff like quick sands may, in many instances, be converted to sound and good standing stuff. After all, where the strata alternate very fast, and have a considerable dip, and any slippery matter like fallers earth or potters clay intervene, adjoining to a porous soil that can supply it with moisture, it is almost impossible to avoid slips, that will prove most disastrous in their consequences, both in expence and delay of the works; as happened in the Tring deep-cutting above mentioned, on the *Gloucester and Berkeley* canal, and many others which we have heard of.

When the engineer has, by a thorough investigation, as above recommended, ascertained the nature of his ground, and its tendency to slip, he can determine what slope the upper banks A B and P K (*Plate I. Canals, fig. 6.*) ought to have in every part; for these ought not to be regulated by the slopes C F and I G, against which the water is to lie, and the waves of the canal to act, but be as steep as the ground or rock will stand, in every considerable length together; and the degree of the upper slopes will be liable to vary accordingly; if these are too much sloped, a waste of land and of labour in excavating and making spoil-banks will be occasioned, while if they are made too steep in slippery or loose wet ground, slips may happen that will occasion still more serious expences, and delay also. All these preliminaries being settled, and the width in every part calculated, a number of slope-holes must be dug at A and P, and a lock-spit dug out to join them, by a careful workman, as mentioned before on the marking out of the canal; and the top-soil being removed and clamped, from a sufficient space for stowing the stuff, the work will then be ready for the contractors to begin digging. This will be our proper place to notice several machines, and contrivances for assisting the operation of excavating of canals, docks, or other deep-cuttings. The most simple and usual method for small depths is by runs of wheeling-planks, supported in an oblique direction up the side of the bank upon horning-blocks of different heights, on which the labourers wheel out the stuff. In larger works, turn-beams or horse-gins are erected on the bank, and a level-stage or scaffolding is erected over part of the deep-cutting; two ropes wind and unwind contrary ways off the drum or barrel of the gin, and pass over pulleys fixed over the end of the stage; these ropes terminate in three smaller ones, two of which have at their ends

rings, and the other a hook, of iron. When a loaded barrow arrives on the run below the stage, a labourer stands ready to slip one of the rings on to each of the handles of the barrow, and to hook the other end into the felies of the wheel; when the revolution of the gin draws up the loaded barrow to the stage above, which a labourer lands, un-hooks the three ropes, and affixes them in like manner to an empty barrow that is to be let down, while a full one is ascending as before, by the other rope. The loaded barrows are wheeled away upon the stage, and run therefrom to any place above that is desired. At the *London Docks*, we saw a very simple method used; two strong posts were set fast into the top of the bank of the dock, at 40 or 50 yards from each other; and at about five or six feet high on each, a large common pulley or ship's block was fastened, by a short length of rope; through these blocks a strong rope was run, whose ends terminated in two smaller ones, with rings at their ends, as before mentioned: the length of this rope was so adapted, that one end reached to the bottom of a very steep run or plane of planks that were laid and fixed on the bank, pointing up to the post at top; while the other end was nearly at the top of another similar plane at the other post. At a proper place between the two pullies, the whipple-tree of a horse's harness was attached or lashed on to the rope. The operation was conducted, by a man arriving at the bottom of the plane with his loaded barrow, the wheel standing at the foot of the plane, the end of the rope being at the bottom of the plane, and the horse standing still near the post at its top; the labourer then slipped the two rings on to the handles of his barrow, and the horse being set in motion towards the other post, the barrow was drawn up the plane, and the man also with it, who made use of his feet, sustaining himself from falling backwards by holding fast by the barrow handles, which he at the same time was enabled to guide; when arrived at the top, and entered upon a plane there of less inclination, the horse had arrived almost at the other post; and while he was stopped, and was turned round ready to return again, by the boy who attended him, the labourer slipped the rings off his barrow handles, and wheeled the same away upon the upper run; another labourer instantly slipped these rings on to the handles of his empty returning barrow, and the return of the horse let him and his barrow down the plane again, the handles going first, and the man holding them as before, but with his back to the barrow; while the other ends of the rope were drawing another labourer and his loaded barrow up the other plane as before. The simplicity, dispatch, and perfect operation of this contrivance, do great credit to its inventor. In very considerable works, it will be attended with the greatest dispatch, as well as ultimate saving of expence, to use trams and temporary iron rail-ways; and if the height and quantity of stuff to be delivered at any one place be very considerable, inclined planes, with steam-engines of small dimensions, (such as are now every day manufactured and improved) should also be erected, to draw up the trams, as at the *London Docks* above mentioned. It is evident, that the simple and straight course for the horse, attached to the middle of a rope as above, may often be substituted for the expensive turn-beams above mentioned, particularly where dispatch in setting the apparatus to work is an object.

Mr. *Rulph Dodd* appears to have contrived a machine to be worked by men, by the means of levers, for excavating canals, which was tried in the year 1794, in the deep cutting at Dawley near Hayes on the *Grand Junction* canal. Mr. *Carne's* machine for the same purpose, but worked by a horse at length, appears to have been used in 1794, in the

deep-cutting near Coston Hacket, on the *Worcester and Birmingham* canal. In the *Monthly Magazine*, vol. ii. p. 594, we have the following account of the operation of *E. Haffew's* patent excavator; "This machine takes the soil from the bottom of the canal, at 40 feet deep, with equal facility as at six feet from the surface! One of them is at work upon the *Gloucester and Berkely* canal. By the assistance of two men only, it removes 1400 loaded barrows from the bottom of the canal, to the distance of 40 feet, in 12 hours; and is so contrived, as to take up the loaded barrows, leave them at top, bring down the empty ones in regular rotation, and leave them at the bottom. It can be moved along the canal to the distance of 26 yards in 10 minutes, by the two men that work it."

In October 1793, Mr. *Joseph Sparrow* took out a patent for a machine, consisting of a box, with its bottom opening on hinges, suspended by a sort of universal gib or crane, the whole moving upon wheels; which he strongly recommends for elevating and discharging the soil dug out of the canal. See *Repertory*, vol. v. p. 77.

Among the most considerable deep-cuttings, are those at Ashton on the *Lancaster*, Tring on the *Grand Junction*, Coston Hacket on *Worcester and Birmingham*, Burbage on the *Kennet and Avon*, Little-borough on the *Rochdale*, Smethwick on the old *Birmingham*, &c.

The construction of Locks is so important a part of canal-making, and they are so very essential to the system itself, that we shall give some brief particulars of their history. Mr. *William Chapman*, in his "Observations on the various Systems of Canal Navigation," has devoted his 7th chapter to an account of the internal navigations of China, compiled from sir George Staunton's and other authentic accounts. He observes, that our pound-locks are unknown in China, (although explained to them by the French missionaries in 1685); and it appears from his account, page 76, that their grand or principal canal is, in fact, only a river or stream navigation, although greatly diverted by art from its ancient course in some parts; the current of the water being slow, and prevented from running off too rapidly by its descent being occasionally checked by flood-gates, consisting of two abutments of stone, one projecting from each bank, and leaving a space in the middle just wide enough to admit a passage for the largest vessels employed upon the canal; and to prevent unnecessary waste of water through the flood-gates, the passages are occasionally closed by planks let down transversely and separately one above another, their ends resting in a vertical groove in each abutment; and he observes, at page 89, that it was probably between the years of the Christian era 605 and 618, that these were introduced. At page 87, he says: "The Chinese method of overcoming ascents appears to be long subsequent to the attempts of the Egyptians, under the successors of Alexander, who, according to Mons. Huet, bishop of Avranches, had the art of constructing sluices, or locks of one set of gates, so as to stop the impetuosity of the current, and be occasionally opened. Though termed gates, the openings were most probably closed with beams of timber, let down in grooves; as gates of large width and depth could not be opened without difficulty, even against a small difference of level. There are, however, such sluices with gates upon several of the running canals on the verge of the *Shannon*. They were erected about the middle of this century, (1750) and are of difficult use, because of the force requisite to open them. These running canals are on the Chinese principle, and nothing more than new channels for a portion of the river; which, when it is low, are stopped as in China, to retain a head of water sufficient to pass the boat." And

Mr. Robert Fulton, in his *Treatise* before quoted, page 7, says: "Machines similar to those of the Chinese have been erected in Flanders, on river navigations, when interrupted by falls, or shoal water; while another mode adopted has been, to erect a dam or wear across the river below the fall, in which were placed two strong buttresses of stone, with perpendicular grooves; after passing the boat above the buttress, a strong gate was let down the grooves, which stopped the water till it ran to a sufficient height to enable the boats to pass." This last description of Mr. Fulton, and which we have also seen in several other places, seems to come nearer to the invention of locks than the others above, which is the reason that we have inserted it, before finishing this subject from Mr. Chapman, who continues at page 88, and says: "These single pairs of piers of the Chinese, are properly called by De la Lande, half-locks. The casual position of two pair of piers near to each other, has, no doubt, occasioned the invention of locks; as it would soon be seen, when the gates or stop-beams of the lower piers were closed, and of sufficient height, that the water would be nearly still between the upper pair of piers, and afford an easy passage. On this principle, in place of single pairs of piers, two pair would be erected, sufficiently near to each other for the purpose, and capacious enough to hold a fleet of boats. It would soon afterwards be found, that in dry seasons the waste of water was greater than could be conveniently afforded, and the operation tedious for single boats; thus would progressively arise the invention of locks with walled chambers, and sluices through their gates or walls. There are at this day existing on rivers locks of the first construction, composed simply of two pair of piers, without any connection of walls or pavement between them." The *Kennet* and the *Lea* have unwall locks. Here we may add, that Mr. Thomas Telford, when projecting the *Inverness* and *Fort-William* canal, on account of the great plenty of water and magnitude of the vessels that are to pass, proposed not to wall the locks the whole length, but to have earthen banks between the two pair of piers of masonry, that support the upper and lower gates of the locks. Mr. Chapman has suggested the paving of the concave bottom and sloping sides of locks, in similar situations.

It appears from M. De la Lande's *Traité des Canaux de Navigation*, that the first lock was supposed to be erected in the year 1488, upon the *Brenta* near Padua; and that shortly after, the two canals of Milan, between which there was nearly a fall of 34 feet, were joined by means of six locks similar in principle to those at present in use. The first lock that James Brindley erected, appears to have been at Compton on the *Stafford* and *Worcester* canal; but they were not at that time uncommon in England on several of the rivers, and on the *Sankey* canal.

A *Lock* or *Pound-Lock* is the connecting part between the two pounds or reaches of a canal, that are upon different levels, and this part, called the chamber of the lock, can at pleasure be made to coincide, in the level of its water, with either the upper or lower canal. This is managed by means of two pair of doors or gates, one at each end of the chamber of the lock; in which gates, or through the side walls of the chamber, are provided small sluices or paddles, by which water can be let from the higher pound to fill the chamber to the upper level, the lower gates being close shut; or to empty the same to the level of the lower canal, the upper gates being close shut: by which means, supposing the lock empty (this term is often used, but it is not to be literally understood, since the lock, when said to be

empty, has the same depth of water in its bottom as the lower canal has), and a vessel or boat arrived on the lower canal, there will be no difficulty in opening the lower gates, and entering the lock, because the water is level and at rest; when entered the lock, the gates are shut after it, and water is drawn from the upper canal by the paddles or cloughs, and in a few minutes the lock becomes full, the boat having risen with the water; when this is the case, the upper gates can be opened without difficulty, the pressure of the water being equal on both sides of them, and the boat can now move forwards on the upper canal. In this state of the lock, we have only to suppose another boat to enter from above, and shut the upper gates after it; when the upper paddles being close shut down, and the lower ones opened, the water will sink in the chamber, and the boat with it, until the lower gates can be opened, owing to the level of the water, and the boat can proceed forwards on the lower canal. The two operations which we have described are called *locking up* and *locking down*.

In *Plate V. Canals*, figs. 36, 37, 38, and 39, we have given a plan and sections of a lock. We have before observed, that the fall at each lock ought to be equal; and the locks ought to be all of one width and length, unless water be in great plenty, and any local trade of a particular kind may require them to be otherwise; because then, a barge in descending through a line of locks will require the same quantity of water at each lock, which we may suppose to descend with the barge, and there will be no water to discharge uselessly by the weirs, or required from feeders, by such a barge during its descent, as must happen in descending through a series of unequal locks. The upper gates of a lock (See the section, fig. 37.) stand on a weir, or wall, as figs. 36 and 37, across the canal, called the breast of the lock, and the place of this is to be fixed by the engineer before the workmen can begin to dig out the ground for the lock; which being done, an inverted arch, with a slight curvature, is turned very sound with bricks or good hewn stones, as a floor to the chamber of the lock, which, if the soil is porous, should have a lining of puddle under it, and should be worked into the side and breast walls: the foundation of these walls ought very carefully to be attended to, and if the ground is not very sound and good, piles must be drove, and the foundations of them secured in the most substantial manner. Instead of turning an inverted arch under, and for some distance within and without the lower gates, two rows, or more, if the soil is very porous or soft, of pile-planking, or dove-tail pikes, are to be drove across the bottom of the lock (as shewn in the sections by 11, figs. 37 and 39.); the length that these are to enter into the ground will, in a great measure, depend on the softness and porosity of the bottom. *Pile-planks*, or dove-tail piles, are stout pieces of narrow elm or oak planks, represented in *Plate IV. Canals*, fig. 30, each having a groove down its side to receive a thin slip of deal or other straight-grained wood, to break the joint, and prevent the water from getting through; the pile A is supposed to be the centre one, on that which is first drove, and is sharpened at bottom by a bevel on each side for that purpose, and shod with iron, if that precaution shall appear necessary; the other pile-planks B, C, D, &c. that are drove in succession, are sharpened to a double wedge, but instead of the acute angle being square to the pile, it is bevelled to about 45°, by which the pile B will be forced close to the pile A as it is drove, and the pile C to B, &c.; by which, and the slips or tongues afterwards put down the grooves, an impenetrable barrier is formed to prevent the water from soaking and softening the

foundation, and at length undermining and blowing up the lock-gates and walls. The heads of the pile-planks should be sawed off very smooth and true after they are drove, and a cross bearer or sleeper is to be nicely fitted to them, and firmly spiked down: other intermediate and parallel sleepers are to be fixed down upon the heads of bearing-piles drove for that purpose, and the whole is to be covered, after the intermediate spaces are closely filled up with bricks and cement, by very sound and nicely jointed planks, that are called the *sheeting* of the lower gates, as shewn in the plan, *fig. 36*, and section, *fig. 37*. Upon this sheeting the lock-fill is to be fitted and strongly fixed down; if the canal is wide, or the fall of the lock considerable, this ought to be composed of two pieces of oak timber, each abutting against the hollow quoins at one end, and meeting at the other in an angle towards the head of the lock, as in the plan, whence such are often called *mitre-fills*. A similar precaution is to be used on the breast of the lock, by driving a row or more of good long pile-planks, with cross pieces or sleepers, and sheeting for the upper gates, on which the lock-fills are to be laid; as also a stout piece of wood, cut to the curve of the breast-wall of the lock, to which it is to act as a coping, to prevent the keels or stems of the barges from damaging the same. It is usual to set out the foundations of the lock-wall straight and parallel to each other, (excepting the wing-walls or return-walls at the end to keep up the earth, and connect with the sloping banks, in the upper and lower canals) and when these walls are arrived at the height of the floor of the chamber, and sheeting of the lower gates, then to begin to batter them back to give them greater strength. On the *Derby* canal we found the locks 90 feet long between the gates; the bottom line of the foundations straight, and exactly $14\frac{1}{2}$ feet apart; as the walls rise they are gradually battered between the gates to 15 feet apart; and in the middle between the gates to $15\frac{1}{2}$ feet, so that the coping of the walls of the chamber of the lock are curved three inches towards the back; and all the best modern locks are constructed on similar principles. Hollow quoins, which are large hewn stones, having a regular curved space cut out of one of their angles, are worked into the walls for the gates to work in, instead of hinges, as shewn in the plan, *fig. 36*; if good durable free-stone is difficult to be procured, the hollow quoins may be composed of very large bricks made in proper moulds for the purpose; and in large works, a large piece of cast iron of the proper shape to work into the wall, is sometimes used instead of quoin-stones or bricks, as at the *London Docks*. The tops of all the walls, locks, bridges, or other erections of a canal, ought to be coped with hewn and well jointed stones, and cramped together; or with large and well burnt bricks of the proper shape, having their top angles rounded off, and set in good cement. Proper buttresses of close masonry should be made to the walls of the lock behind, to give them greater strength, and to tie them more effectually into the bank, and to break the regularity behind, so that if water should leak through the walls in any particular part, when the locks are filled, or allowed to stand full longer than is proper, such water may not connect together in a large extended sheet, to act by its hydrostatic pressure in overturning or bulging in the walls, of which we have read and seen so many instances. A proper space behind all the walls should be puddled, allowing each course to set effectually before another is applied; and provision must be made, in carrying up the walls, for crooked culverts, each of 14 to 20 inches or more in diameter, according to the supply of water and dimensions of the lock, called the *paddle-holes*, to extend from near

the floor of the chamber of the lock, behind the walls, and rising up, so as to return into the lock again behind or above the upper gates; its plan being shewn by dotted lines *ee*, in *fig. 36*, and its vent, or lower end *e*, is seen in the section, *fig. 37*, as its mouth or upper end is in the section, *fig. 38*; in the latter case, one of them being shewn open, and the other closed by its paddle or clough. A recess is made in each wall above the several hollow quoins, large and deep enough for the gates to open back into, and remain out of danger from barges passing into or out of the lock, as shewn in the plan, *fig. 36*. In the recesses belonging to the upper gates, a weir or over-fall, *ii*, *fig. 38*, for the water, is provided, four or five feet long, having a coping or sill of good stones or bricks, just the height at which the water is intended to stand in the upper pound or canal; these are called the *paddle-weirs* or *lock-weirs*; a large flat stone is usually laid over these, leaving three or four inches in height for the stream of water, to complete the wall upon, and the cavity is conducted down, diminishing in width and enlarging in depth behind the walls of the lock, into the paddle-hole, or crooked culvert before mentioned. The construction of the paddle-holes and weirs deserves the particular attention of the engineer, to see that they are constructed of the very best bricks, laid in good cement, and the same allowed to set thoroughly before the canal is filled; or the rapidity, and frequent action of the water in these parts, will wear, undermine, and endanger this part of the lock.

We may proceed now to describe the other appendages of the lock; these are the lower gates, which ought to be constructed of stout oak framing, the head or hinge post of the gate being rounded and nicely fitted to the hollow-quoins above described, while the other heads are carefully chamfered off, so that when the gates are set up in their places, touching the hollow-quoins, and the mitre-fills, their chamfered heads shall meet and truly fit; instead of hinges, either a rounded part of the head of the gate, or a strong gudgeon of iron at the bottom, is let into a hole provided in the stone or timber below, but not fitted thereto so as to bind, or prevent the rounded part of the head from being pressed closely and uniformly into the hollow-quin by the force of the water; the top of the gate is kept in its place by a strong strap of iron which goes round it, allowing sufficient space, and is keyed or screwed down to a strong cramp or pin in a large stone, which acts as a coping to the hollow-quoins. The gates are usually planked with deal, sometimes upright, but often in a diagonal direction; and a square hole is left in the boarding of each lower gate, to which a paddle is adapted, with its stem or rod rising up above the top of the gate, by the side of a standard of wood, *k*, *fig. 39*, fixed to the top rail or balance beam of the gate in which is a pinion, working into a rack of cast iron on the paddle-stem, which is turned by a winch-handle, and the paddle is retained at any height to which it may be drawn, by a ratchet or stop, that can readily be turned up to lock into the teeth of the rack, or turned down to discharge and let down the paddle. The top piece or balance beam is usually a tree of considerable dimensions, having its full size, or but end, left unhewn to act as a handle to turn the gate round by, and at the same time to balance it, so that the front of the gate may not drag on the sheeting at bottom; but as it would be very difficult thus to balance large lock-gates, like those at the *London Docks*, a roller of brass or cast iron is fixed under the head of each gate, and a strong circular sill of wood, or rail of cast iron is prepared on the sheeting, for the same to roll freely

upon, and cause the gate to open and shut easily: the height of the roller above mentioned is made adjustable by a screw, so that the gate can at all times be kept from dragging on the sheeting: and instead of handles to open such gates, ropes and chains, and capstans, erected on the banks for the purpose, are used to open and shut them. The upper gates are hung and constructed nearly like the lower ones, except that they have no paddle-holes in them, and are usually boarded no higher than the level of the paddle-weirs behind them, in order to assist as weirs in carrying off a superfluity of water; but these are often attended with bad consequences, the fall of the water wearing, and in time damaging the breast of the lock; and in floods, the stream or splashing of the water may damage goods in, or even endanger the linking of, heavy laden boats, in the lock; the same may also happen with deeply laden boats when the paddles are drawn in ascending, if the paddle-holes do not enter the chamber of the lock at some distance below the surface of the water, and in a proper direction: on the *Monmouth/Bire* canal the paddle-holes are both united, and discharge themselves through the breast of the lock into the chamber; a practice that seems by no means worthy of imitation. The upper paddles, or those behind the upper gates, are drawn by a rack and pinion, *k*, *fig.* 38, by means of a winch-handle, (which each bargeman and lock-keeper carries with him) in the same manner as those in the lower gates, which we have described above. Guard-rails or curving pieces of timber, *f*, *fig.* 36, ought to be strongly bolted on to piles driven for that purpose in the front of the wing-walls just above the surface of the water, to guide the boats into and out of the locks, without striking the walls; which is far preferable to the huge stones let into the wing-walls in some places, called bumping stones, and calculated rather to break and destroy the barges, than protect the walls. It will be necessary also to provide a strong piece of wood formed to the curve of the breast-wall of the lock, *b*, *fig.* 37, before which it should be suspended a few inches above the water when the lock is empty, by means of two or three chains; these are called bumping pieces, and are intended to receive the stem of the boat, and prevent it striking the wall when the same is not strapped or stopped in proper time; a practice, however, for which the bye-laws or clauses in the act should provide adequate fines or punishments: and strapping posts should be set firmly into the ground in the proper places for the bargemen to wind their rope, or strap as they call it, and by easing it out by degrees, to stop the velocity of the boat before it arrives at the gates or breast of the lock that it is entering. The gates should also be furnished with two or three strong upright planks on the lower side, *g g*, *fig.* 39, to receive occasional blows from the noses or items of the boats, and prevent the planks of the gates being broken or started thereby. There is room for the skill of the engineer to be exercised, in forming the lock-fills and gates to that particular angle which will render them stronger for the same width and depth of lock, than they would be if they met more acutely, or were shorter and met more obtusely. In very large and wide locks, the gates should not be straight or plane, but a little curving to give them greater strength. On narrow canals, it may not be necessary to make double or angle gates, but one gate shutting square across the lock may be strong enough to answer every purpose, and be opened more readily than two gates on the opposite banks can be; the upper gates in particular, on account of the comparative shallowness of the water there, may be single, while the lower gates, if the fall is considerable, may be double. In setting out canals, where the fall

of the ground is very gradual and easy, it may be necessary to avoid long lengths of deep-cutting below, and of embanking above, or making the line very crooked, to make shallow locks, if water is plenty; and under the same circumstances only, will it be allowable to make 10, 12, or more feet locks in particular places, however well the ground may suit the same; many of these double locks were at first erected, as on the old *Birmingham* canal, and the *Calder and Hebble* navigation, where about 1783 single locks were obliged to be substituted, to avoid the waste of water, before pointed out.

We have not yet noticed an inconvenience and waste of water, which attend the placing of locks nearer to each other than about 100 yards, or having basins between them, equal in area to about that length of the canal, as was done at *Salter Hebble* in 1783 in the alteration above mentioned; without which precaution, a boat in descending lets down more water than the pond below will hold, without raising its surface so as to lose a good deal over the lock-weirs, and still worse happens in ascending, for the short pens are so much lowered by filling the lock below, that laden boats are unable to proceed for want of water, until a supply is let down to waste, through the upper lock, to help them forwards. As many locks as can conveniently be brought near to each other, on the principles above, and before explained, should be contrived, if it can be done, to be in sight of each other, and of a length of canal each way; and the lock keeper's house should be so placed, that he can when at home at his meals, or otherwise, in bad weather, see barges approaching the locks, in time to meet them before they enter the locks. Mr. *Fulton* who wrote in 1796 says, that the cost of locks for 25 ton boats, was about 70*l.* per foot rise, and for 40 ton boats, about 100*l.* per foot rise; this may serve to give some general idea of the cost of locks at that time; but we would observe, that the decrease of the value of money, and the exceptions to all general rules on these subjects are so many, no dependence ought to be placed on such modes of estimating. If sufficient water-way is given in the paddles, and there is assistance enough to draw both the paddles, and open and shut the gates at the same instant, a boat may pass each lock of the usual construction and rise, in three minutes time, but in general, 5½ minutes will be nearer to the average time lost at each lock, as observed by Mr. *Bevan* on the *Grand Junction* canal. Theorems for the time of filling a lock of given dimensions, and with given paddles and fall of water, should be found and compared with many experiments on the locks under the care of our resident engineers. (See *Nicholson's Journal* 8vo. N^o 9, vol. iii. p. 30.) It should be considered, that a boat going up lets down or consumes twice the weight thereof (boat and cargo included) in water, more than in going down through each lock; for the boat on entering the empty lock, expels as much water into the lower reach as its own draft of water, which is made good out of the upper pound when the boat enters the same; while a descending boat expels its own flotation bulk of water from the full lock into the upper pound, where it is retained on the shutting of the upper gates; the mean of a passage each way will be a lock-full for each boat, unless they go always loaded one way, and empty the other. Mr. *Fulton* says, that the consumption of 25 ton boats through eight feet locks, will in general be about 103 tons of water in ascending, and 103 tons in descending; and Mr. *Chapman* informs us, that boats passing and repassing a summit, laden one way, and returning empty, will require nearly 13 times the weight of their lading of water for their lockage, out of the summit

pound. Seven hundred tons of lading per day are as much as pafs or repafs upon any one of our canals, according to Mr. Fulton.

We cannot with propriety quit the fubject of constructing locks, without mentioning *coffer-dams*, which are a double range of piles drove very clofe to each other in a circular form round the mouth of any canal or dock, that is to have a lock built, repaired, or altered, connecting with the fea, a river, or any exifting navigation that cannot be emptied of its water; the interval between the piles being filled with earth, the water in the fpace between the coffer-dam and the intended works is then pumped out for the works to proceed; the many and fatal accidents to which thefe are liable, efpecially when the works are nearly completed, and the earth is excavating from the bottoms to open the paffage freely to the lock or works, require all the precautions, fkill, and attention of the moft able engineers, efpecially when the rife and fall of the tides or waves of the ocean, prefent unequal action on the piles and dam.

The *faving of water in the ufe of locks* is a confideration of fo much importance in moft of the inftances which occur, that it is neceffary we fhould mention feveral of the expedients which have at different times been propofed, or practifed for that purpofe. Some of the moft obvious of thefe are, a minute attention to the fitting of the gates and paddles, constructing every part of them of the moft feafoned and durable materials, with the utmoft precautions againft partial wear or liability to accidents, by which the gates or paddles would leak and wafte the water; and fhould fuch leaks happen, the eftablifhment for working the canal ought to be fuch, as to detect the fame immediately, and apply the proper repair or amendments without delay. It is of great importance to adapt the plan or furface of the water in the lock, to the fize of the boat or boats that are to be ufed, leaving as little water uncovered in the chamber of a lock as poffible, and for this purpofe, where water is fcarce, it will be neceffary to enforce the regulations, that the act ought to contain for the length, width, and form of the boats that are to be ufed; and on canals for large and fmall boats, to fee that two or more of the fmall boats are fo contrived as to lie clofe together in the lock, and occupy the whole fpace thereof as one of the large boats would do: lefs than this number of fmall boats muft not, when water is fcarce, be allowed to pafs, or without paying fuch increased tonnage or lock dues, as will act like a prohibition.

The *waiting for turns*, particularly by empty or lightly laden boats, ought alfo to be provided for, and it may be neceffary on fome occafions to enforce the fame; viz. to fuffer no boat to pafs down, until there is another arrived below, and ready to afcend as the lock is filled; or any boat to afcend, till another is ready above to defcend with the fame lock-full of water. Where fmall or fhort boats are in pretty general ufe upon a canal, as on the *Shrewfbury*, it may be right to adopt the practice which Mr. Thomas Telford has defcribed, who fays, "the locks are fo formed as to admit of either one, three, or four boats paffing at a time, without the lofs of any more water than what is juft neceffary to regulate the afcent or defcent of the boat or boats that are then in the locks. This is accomplished by having gates that are drawn up and let down perpendicularly inftead of being worked horizontally; and each lock has three gates, one of which divides the body of the lock, fo as to admit of one, three, or four boats at a time." See *Plymley's Report* before quoted, page 2.

A very fenfible writer, who has given a full account of

the *Grand Junction* canal, in the *Agricultural Magazine* for 1803, vol. viii., under the fignature of a conftant reader, fuggefts at page 204, the propriety of an additional fet of narrow locks on each fide of the fummit which is in want of water, for the ufe of the narrow boats, to which they fhould be exactly fitted; as alfo, to avoid the expence of lifting or pumping water, that can be collected in refervoirs or feeders at fome diftance below the fummit level, by ufig shallow locks of only three or four feet rife each, between the fummits and the points where fuch waters can be taken in without lifting. The pumping of water from a lower level to fupply the wafte of lockage, by means of fteam engines, has been practifed with fuccefs on the old *Birmingham*, the *Darnley*, and feveral other canals; the *Croydon* was to be contructed with a dependence on this mode of fupply, as appears by its act; and on the *Grand Junction*, engines have lately been erected near Tring and near Braunfton, for raifing water to the fummit-levels. A very confiderable power is loft in the defcent of the water through the paddle-holes, to fill the lower part of a lock, and again through the gate paddles in emptying the upper part of the lock; we have often thought that it might be practicable to apply this power for returning a certain quantity of water into the upper pound, either by making the defcending fream act on a wheel, or on vanes like thofe of a fmoak-jack, or by means of hydroftatic prefure, or momentum machines. See *Monthly Magazine*, vol. vi. page 124.

Side-ponds are an expedient for retaining part of the water, from the upper part of a lock when it is to be emptied, and to ufe the fame towards filling the lock again for the next boat: they are faid to have been invented by M. Dubie, and one with 3 divifions was tried in a lock of 20 feet fall, on the canal of *Tpres*, near 100 years ago; they are defcribed by M. Delidore. On the 5th July, 1791, Mr. James Playfair took out a patent for this mode of faving water in ufig locks. See *Repository*, vol. iii. 303. And in the fame work, vol. i. p. 377, Mr. W. Pitt has defcribed three fide-ponds, in form of fectors of a circle. We read that in April laft, (1805) an experiment was made on the *Grand Junction* canal, and two of thefe fide-ponds, with earthen banks like a canal, and each about the fame fize as the lock, were tried near Berkhamfted; into one of them, whole bottom coincided with about half the height or altitude of the lock, the upper quarter of the water of the lock, for a defcending boat, was drawn, and it was there retained by a clofe fhuttle; the fhuttle of the other fide-pond, whole bottom was about level with one-fourth of the height of the lock, was then opened, and about another quarter of the water in the lock flowed into it, and was there retained by the fhuttle: the remainder being emptied by the gate-shuttles into the lower canal; and the boat having paffed out, and another afcending one taken its place in the lock, the fide-pond that had laft been filled was emptied into the lock, and then that alfo which had been firft filled; thefe together filled half the lock, before the upper paddles were drawn to fill up the remainder, the fhuttles of the fide-ponds being firft fhut down; by this means, two boats were paffed, by letting down only half a lock-full of water into the lower pound; and the lock remained full, ready for another defcending boat, as before. The time taken up by the above operations was about nine minutes for each boat that paffed, or 3½ minutes more than if the fide-ponds had not been ufed. We underftand that fide-ponds are becoming common on different canals; their construction offers a very curious exercife for the abilities and fkill of the engineer, fo to apporportion the number, fize, and height of the ponds, that, confi-

dering the expence of construction, loss of time in passing, and the saving of water that is effected, the result may be the most advantageous.

It appears, that Mr. *Michael Logan* took out a patent in 1804, for raising or forcing water into a lock; also, that in January 1791, Mr. *Joseph Brooks* obtained a patent, for a method of drawing up the false or moveable bottom of a deep side-pond or large well near a lock, and by that means filling the lock with water, until a barge had passed up, or another was ready in the lock to descend, when the false bottom being again let down, the water retreated by the same connecting culvert that had brought it into the lock, it was again emptied, and the boat able to proceed on the lower canal, without having waited or let down any water. See *Repository*, vol. vii. p. 361.

Mr. *Lawson Huddleston* has communicated, through the medium of *Nicholson's Journal*, 8vo. vol. iv. p. 236, a method of raising the water in a lock, from a deep side-pond or well as above, by means of a solid or heavy plunger that can be let down into the well, by means of machinery that suspends it, when the water is to be raised, and drawn up when it is to be allowed to sink again; the plunger being balanced in all its different degrees of immersion by a counter weight acting on a snail or spiral curve.

Mr. *Robert Salmon* has invented a different mode of accomplishing the same thing; his plunger being hollow, and as buoyant as possible; and for forcing the same down into his cistern or side-pond, when the lock is to be filled with water, he has contrived a very curious apparatus; it consists of a very heavy carriage on four low wheels, or heavy rollers of metal, connected together by a frame to answer the same purpose. Two frames or planes are prepared, that turn on fixed centres, as a door does on its hinges, but horizontally instead of vertically; the other two ends of these planes rest on the two ends of the plunger, by means of uprights therefrom and moveable joints; upon these planes the carriage rolls, in such a manner, that when it is drawn forwards, by means of a rope or other machinery, the weight advances upon the plunger, and the planes being at liberty to turn on their joints, it sinks the plunger by degrees, until at length the four wheels rest exactly over the joints at the ends of the plunger, exerting the whole weight of the wheels and carriage, to keep it down and elevate the water in the lock; on the carriage being withdrawn, the weight on the plunger lessens, and it rises, until at length the four wheels rest just over the hinges or fixed joints, and no part of the weight of the carriage or wheels is then exerted upon, or to counteract the buoyancy of the plunger, and the water retreats from the lock into the space under the plunger. That this carriage, which must be extremely heavy for large locks, may not be subject to run forwards or backwards on the planes; Mr. *Salmon* has contrived one of them with a peculiar curvature or bend, so that the tendency of the carriage is as great to advance as to retreat, in every part; and a constant and small weight, hung on the end of a line over a pulley, in the model, will cause it to move either way, with a regular and steady motion. During the last session of the *Society of Arts*, in the *Adelphi*, Mr. *Salmon* presented a model and description of his invention, for which he was honoured with a premium; the model is lodged in the Society's collection, for public inspection, and a particular description of the same is expected to appear in their next, or 23d volume of *Transactions*. Mr. *Salmon* has hit upon a method of mechanically constructing the curve above-mentioned for one of the planes, which is found to approach very nearly to the arc of a

circle. A mathematical friend of Mr. *Salmon*, who was shewn the model in an early stage of his experiments thereon, has proposed as the 84th question in *Leybourn's Mathematical Repository*, the determination of the nature of the curve in a particular application of Mr. *Salmon's* principle; we are sorry, however, to see this question still unanswered by the ingenious correspondents of that very useful and learned work; because this curve promises to be applicable on several occasions in the construction of hydraulic machines. We have been treating of various contrivances for saving water in the use of locks of the common construction; and we shall now proceed to mention several substitutes for locks in overcoming ascents on a canal or river, but in which the boat continues floating in water; before we proceed to inclined planes, or other schemes, in which the boat is to be drawn or suspended out of the water, or the goods to be removed by cranes, &c. to other boats.

Substitutes for locks, have been called for in some situations by the actual scarcity of water, in others by the previous and necessary appropriation of the whole of the streams to mills or the practice of irrigation, and not in a few cases by the jealousy and opposition of mill, park, and land owners; the intemperate zeal also of some projectors may have operated, who do not hesitate to prognosticate the annihilation of lock-canals, by "improved science; in like manner as improvement in machinery renders the old apparatus useless." See *R. Fulton's Treatise*, page 28 and 110, &c.; also, *W. Chapman's Observations thereon*, page 2, &c. Several canals have, like the *Hastingsden*, been restricted from erecting locks in particular places, without the mill-owners' consent; it is therefore no matter of surprise, that various schemes have been proposed to obviate the necessity of common locks. On rivers where the boats are hauled up against the stream, it is not unusual to lighten a boat by shifting part of its cargo into other boats, called lightening boats, so that their diminished draft of water may enable them to be dragged over any particular rapid; and in more extreme cases, the whole of the lading may be taken out, and be conveyed by land to meet the boat again after it has been dragged empty over the rapid. Rapids may themselves often be made navigable by jetties, or contraction of the width of the stream in such places, and if the fall is rendered very considerable thereby, capstans or machinery may be erected for the hauling up or easing down of boats; these methods have doubtless been in use from the earliest periods; and we read of great numbers of men in China being employed with ropes to haul boats up their artificial rapids or falls. The methods of using stop-planks occasionally to cause an artificial flood in Egypt, China, Flanders, and Ireland, as before-mentioned (when speaking of the invention of locks), are also very ancient, and such are still in use upon several of our rivers; on the *Fuel* river below Biggleswade, we think we remember seeing upright narrow planks used against a moveable beam at top of the water, and a fixed sill at the bottom of the same, for penning the water and producing a flush or flash of water, when the planks are removed and a boat is to pass. On most of our old river navigations there are gates erected to pen the water, and the same are drawn up to occasion a sudden flash while a boat is to pass. At the entrance of the *Worsley* mine on the *Duke of Bridgewater's* canal, we remember a large door that was drawn up for our boat to pass under it into the tunnel, and then let down to pen the water therein three or four inches higher than it stood in the canal. The difficulty of opening large gates, to produce a flush of water or to let a boat pass

has been before noticed; and in the *Memoires de l'Acad. des Sciences* for 1707, we find the description by *M. de la Hire* of gates calculated to obviate this inconvenience in part, by having a large pair of doors in the gates opening the contrary way, or with the stream, which on the drawing of a pin can be let to open by the pressure of the water; after which the great gates can be opened with ease, and when open, the doors can as readily be shut again and pinned, owing to their standing in the direction of the stream; and the gates then are ready to be shut again as soon as the head of water is run off, or the boat has passed. It appears, that in extending the navigation of the *Seine* river in France, gates were introduced, which the Duke of *Rouanez* had invented, and which are described in the *Memoires de l'Acad. des Sciences* for 1669, consisting of two upright gates, rather wider than half, and as deep as the channel of the stream or river, bent into the arc of a circle of about 48 feet radius; to each of these gates several long beams of wood were fixed, meeting in or near the centre of the circle, of which the gates formed a part; and here being firmly united, they abutted against a solid pier of stone, or worked on a centre-pin fixed in a strong pile, drove very firmly into the earth by the side of the channel, at 48 feet below the place where the gates were intended. A notch was formed in the bank of the channel on each side, in form of sectors of circles, sufficiently large to contain the two gates and their beams or centering as above. By this construction, the whole of the pressure of the gates when shut and the water penned by them, was brought to act on the two upright pins or centres; and a very moderate force applied to the head of each gate would draw them apart and into the sector-like recesses prepared for them, leaving the channel or course of the stream perfectly free of any obstacle, to check either the current or a boat in passing through. By a small adjustment of the places of the centres, gates of this kind may at all times be made to fit close to each other in the centre of the channel, on its bottom, and also to the side walls of the channel above them, and yet on being moved a small space from each other they may clear those walls and be free to move into the recess, in the bottom of which there may be small rollers to carry the gates with less friction, or rollers under the gates may be used for the same purpose. See *Jacob Leupold's Theatrum Machinarum*, folio, published in 1726 at Leipzig.

Dr. James Anderson, of Edinburgh, has contrived, and published in 1794, in his *General View of the Agriculture, &c. of the County of Aberdeen*, a method of elevating or depressing small boats, floating in a coffer or large tight open case full of water, that can at will be made to coincide and connect at one of its ends with either the upper or lower canal; into or from which the boats may pass without the loss of more water than is necessary to fill the narrow space between a draw-gate at the end of each canal and at the ends of the coffer, when the same is pressed and retained close to the end of the canal, and a small additional quantity to restore the equilibrium and give motion to the coffers, of which there are two exactly of similar dimensions suspended and connected together by strong chains. *Mr. Chapman's* concise description of this invention is so much to our purpose, that we beg to use his words, who says, "the doctor there observes, that, for all the purposes of commerce, no more width of boat is requisite than four feet, or more than two or three feet depth; and that the length might be indefinite, so as not to be inconvenient for ascending and descending between any two levels of canal, which he proposes to be done in the following manner, viz. that the lower level be

run up to nearly under the end of the upper, and terminate by an upright end and two side walls of masonry, to the full height of the fall, with a pier in the middle dividing the passage between the two side walls into two openings of rather greater width than the boat; the two ends of this pier are to be elevated so as to sustain the axis of a wheel, of a diameter equal to the width of the pier, and half of each opening. A chain passing over the wheel suspends from each end a rectangular case, so hung, that when one shall be at the bottom ready for a boat to float into, the other shall be at the top, and close pressed to the wall or frame at the end of the canal, so as to prevent the escape of water; then, by opening a stop-gate at the end of either canal, and another at the corresponding end of the case, it is obvious that the boat may float in or out. The lower boat and case (or case with water only) are then in a kind of lock just containing the case, and of sufficient depth to permit it to descend to the level of the lower canal. From this lock there is a conduit to keep the water down below the canal bottom. These are the outlines of the invention, which, where the connection between the two levels is a precipice, or so steep as to require only a short tunnel to the well or pit, up or down which the boats are to move, may, on receiving such improvements as it is capable of, be easily carried into effect for small boats, for which the author alone proposes it. It is obvious that under other circumstances, as to situation, the expences of high embankments above, of deep sinking below, and of bringing up the conduit to lay dry the lower locks, must more than counterbalance any advantage than can be derived from it." Where the fall is considerable, the doctor has proposed a balance chain, of the same weight per foot as the suspending one, to be hung from each coffer or case. See *Repository*, vol. ii. p. 21.

On the 24th December, 1798, *Mr. James Fuffell* took out a patent, (see *Repository*, vol. xi. p. 7.) for a method differing in principle from that of *Dr. Anderson* above described, only in having an axle and two wheels thereon, at a distance from each other on the middle pier, and under his coffers or receptacles, similar axles with a pair of wheels, and instead of his coffers or receptacles being suspended from the two ends of a chain passing over the wheel, as in *Dr. Anderson's* method, *Mr. Fuffell's* two chains are fixed to the tops of the side walls, passing under the wheels of his receptacles, and over the wheels and axle on the middle pier. He also describes rollers or guides by the sides of his lock-pits to steady the receptacles, and a toothed wheel on the middle shaft or axle connected with a fly or brake wheel to regulate the motion of the chains and receptacles; he also proposes the gates or hatches at the end of his receptacles, to be balanced by counterweights, and to draw down into a cavity prepared for the purpose, when a boat is to be passed in or out, instead of drawing up. And if the fall be very considerable, he suggests the propriety of a short tunnel or arch to conduct the lower canal into the lock-pit, instead of an open notch or perpendicular walled cut in the hill for the lower canal. It appears that this balance-lock of *Mr. Fuffell's* was put in practice, or at least tried, on the *Dorset and Somerset* canal, near *Froome*, on the 6th of September, and 13th of October 1800, on a 21 feet fall, and with boats of ten tons burden; delays in completing the above canal, and forming a communication, prevented this lock from being made use of for a long time afterwards; but we believe that the note of a late writer on the above experiments, stating that a subscription was set on foot in 1802, to raise money to make a lock in this very place, originated entirely in mistake.

On the 18th of March, 1794, *Messrs. Rowland and Pick-*

ering, took out a patent (see *Repertory*, vol. i. page 81.) for a coffer or cradle similar to those described in *Anderson's* and *Fuffell's* methods above, but which, instead of being suspended from or on chains, is, in this method, supported on pillars by a large diving-chest or caisson, sunk in the water of a pit or well underneath, the whole being so balanced, that the cradle can be brought to coincide either with the upper or lower canal, when boats are to be floated in or out of the same. *Mr. Chapman's* short description of this invention is as follows: "Messrs. Rowland and Pickering's plan of enabling great boats to ascend and descend with inconsiderable waste of water, consists in having at the head of the lower level of canal, a pit sunk as much below the bottom of it as the difference of height between the two levels, added to the depth of a covered caisson of requisite magnitude. This caisson, when immersed in the water, with which the pit is filled to the level of the bottom of the canal, is to support on wooden or iron pillars, of height equal to the fall between the two levels, a trough or cradle with gates or draw-doors at each end, containing a sufficient depth of water, to which the floating power of the caisson must then be in equilibrium, and consequently capable of moving with ease between the top and bottom of the pit. When the surface of the water of the cradle is level with either of the canals, and the end of it is closed against the framing of the gate of the canal by screws or other means, and the water let in to fill the vacancy between the gate of the cradle and that of the canal, they both may then be opened, and a boat be admitted to pass out. Excepting what may if necessary be used for regulating the equipoise and change of motion; the intermediate water between the gate of each level and that of the cradle, is all that is consumed, and with draw-doors to the cradle and single gates to each level as already premised, the quantity must be very trivial. The weight of water displaced by the bulk of the pillars sustaining the cradle need not be material; and where requisite, it is proposed to be counterbalanced by weights acting on a spiral wheel. This plan, which possesses ingenuity, and is applicable in many instances, is now carried into execution on the *Ellesmere* canal, near Ruabon, in Denbighshire, on a fall of 12 feet, and for boats of 70 feet length and 7 feet width; the whole is moved up and down by a rack and pinion towards each end of the machine." We may add, that *Rowland and Co.'s* patent describes four ropes to be attached to the corners of this cradle in some instances, passing over pulleys in a framing above, to which weights are to be suspended for assisting the buoyancy of the caisson, or even in some instances to supersede its use altogether, in balancing and moving the cradle up and down. The three methods last described, as the inventions of *Anderson*, *Fuffell*, and *Rowland and Co.* are called *Balance-locks*.

On the 19th of June, 1792, *Mr. Robert Weldon* took out a patent, (see *Repertory*, vol. ii. page 235.) for a *Caisson-lock*, consisting of a long covered and close caisson or trunk, with close shutting doors at its ends, in which water enough is contained for a boat to float into it, when it coincides with the surface of the water of the upper canal; when being shut in, this caisson or diving-trunk containing the boat, is to be sunk through a deep pit to a door or valve opening to the lower canal, and the end of the caisson being fixed closely and exactly against the opening of the same, it, as well as the door of the caisson, is opened and the boat passes out into the lower canal, and the apparatus is then ready for another boat to enter and ascend in like manner. *Mr. Chapman* thus describes one of these caisson-locks for a fall of 45 feet, and for boats of 72 feet length and 7 feet width: "The caisson or chest is cylindric, and in this in-

stance of sufficient strength to bear the pressure of a column of water 45 feet or upwards, to which it is subjected when opposite the lower level, on account of the necessity of its being covered when opposed to the entrance of the upper level. It is so balanced, that when it has sufficient water within it to float a boat, it is of the same specific gravity as the medium it floats in; and, like an air balloon, it ascends or descends by a slight increase or diminution of its relative gravity, which, in this machine, is done by raising out or admitting an inconsiderable quantity of water. The pit in which the diving chest moves, has, opposite each level of canal, a tunnel or opening closed with gates, and is so much higher than the upper canal as to contain a height of water just sufficient, as already mentioned, to cover the caisson when opposite the upper level. In this or in its lower position, when run close to and abutting against the entrance, it is retained by the water being let out of the short part of the tunnel between the gates of the level and the end of the caisson. It is then held there by the pressure of the column of water intervening between the surface of the water and that of the canal to which it is opposed. The gates of the level of the caisson are then opened, and the boat goes in or out, and on the gates being again closed, and the water let into the vacancy, the diving chest is ready to proceed to the other level. This scheme possesses much originality, and may often be usefully applied." The patent describes racks and pinions, or chains and pulleys, for regulating the motion of the caisson in its ascent or descent through the water, and describes the gates of the upper and lower level of the canal, as sliding up into proper recesses by the motion of a rack and pinion, when the caisson by settling opposite it, has removed the pressure of the water in the lock-pit, and that pumps are to be used by the boatmen, who are shut up in the caisson on board their boat, for expelling or admitting water to lighten or weight the caisson, and air-pipes to prevent accidents by the want of fresh air, in case of any delay while the caisson with the men in it are under water. It appears, that the first of these caisson locks was erected in 1794, for an experiment, by the side of the canal at Oken Gates in Shropshire; and that about August 1796, one was begun in Combe hay, on the Dunkerton branch of the *Somerset* coal canal, having the fall and dimensions above described; about December 1797 it was completed, and was several times tried and boats and men passed through it, among whom was *Mr. William Smith*, the resident engineer; the trials continued occasionally during the spring and part of the summer of 1798, the canal not being ready for its being used by the trade; when it was discovered, that the walls of the lock pits had not been constructed with the requisite care by the contractor and inventor under whose directions they were built, but the water had got behind them, and on drawing off the water to make some alterations, they bulged so much, that the whole was rendered unsafe and useless. After which the company substituted inclined-planes for removing coals, &c. in boxes to other boats at this place; but since which, locks have been constructed in their place.

Before we quit those contrivances in which a boat and its lading are to be transferred floating in water, we have to mention an ingenious suggestion of *Mr. William Chapman*. He proposes, (*Observations*, p. 85.) that a caisson containing water and a boat thereon should be drawn *side-ways* up a steep inclined plane, to be counter-balanced thereon by weights, or water-tubs descending down pits prepared for that purpose, or by another similar caisson on another plane. We find also in *Mr. Jo. Fuffell's* patent (*Repertory*, vol. xi. p. 12.) the mention of caissons with boats floating in

them, being raised and lowered by the double chains of his particular construction, on double inclined planes, wheels, axles, &c.

The construction of *Inclined Planes*, on which boats are to be drawn up or let down from one level of a canal to another, appears to have been long known in China. Between the upper and lower levels of their smaller canals, a double glacis of smooth hewn stone is constructed; the principal slope of this extends from the bottom of the lower canal to a little above the surface of the water in the upper canal, and terminates in a large beam of wood across the plane, the top of which is rounded and made very smooth, from which another similar plane of stone descends to the bottom of the upper canal. The bottoms of their boats appear to be flat, and constructed so strong and smooth, that a boat and its lading can be dragged up one of these planes, and lowered down the other, in order to pass forwards on the canal. The amazing populousness of China rendering manual labour very cheap, men are employed in incredible numbers for working their canals; a rope is said to be hove round the stern of a boat that is about to ascend one of these planes, and by means thereof she is dragged up the plane either by hauling directly at the rope, or by passing its ends round capstans erected for the purpose on the banks of the larger planes, to the bars of which the men apply their strength. When the boat is brought to an equipoise on the cross-beam, another rope is dextrously slung round the head of the boat by means of which it is eased or let down without violence into the upper canal; the same process is used in descending. It seems a matter of doubt, whether cradles or rollers of any kind are used under the bottoms of the Chinese boats, while they are passed over their inclined planes, as the latest accounts of travels through that surprising country, make no mention of such. Water-wheels have also been described by some as in use there, for raising and lowering their boats, instead of capstans worked by men; but of this also there are perhaps reasons to doubt.

The *Ponts aux Rouleaux*, or rolling bridges, which are particularly described in a tract printed at Paris, in 1693, are said then to have been practised for some time in Holland with success, particularly on the canal between Amsterdam and Sardam. This kind of inclined planes had rollers at short distances, over which, by means of a water wheel, the boats were hove up to the ridge separating the two waters, a little higher than the upper one, and were launched or let regularly down to the other. Mr. Chapman observes, that the boats in this and the Chinese method, could not be very long, because, although here in ascending or descending the inclined plane, they might bear upon many rollers; yet, in the change of position from the regular line of ascent, they must obviously bear upon one roller, and be liable to strain.

Mr. Davis Dukart, an engineer in the Sardinian service, was, as Mr. Chapman informs us, (*Observations*, p. 5.) the first who introduced inclined planes into practice in the British dominions; he resided in Ireland for some years previous to 1777, and was engaged in the Tyrone collieries near Dungannon, which are situate about three miles distant, and 200 feet above the level of the canal connecting with Lough Neagh; the sums granted by government being inadequate to the construction of locks for so great an ascent, Mr. Dukart turned his attention to small boats and inclined planes, of which he constructed three, connected by narrow canals. The falls were 70, 65, and 55 feet, which last terminated about 15 feet above the canal; to which, by a short rail-way, his boats, again floating over a carriage, were drawn onwards to the wharf: and there, being supported on

gcecs and frames, the boats were turned over to discharge their cargoes. This first attempt differed from the *Ponts aux Rouleaux* in no other respects than having a double passage down the inclined planes, so that by means of a rope leading over a wheel, his loaded boats drew up his light ones; but finding various inconveniences, from some of the rollers not turning, and from the individual irregularities of the diameters of others throwing his boats to one side, as well as from other causes; he suggested and put in use an inclined plane with two parallel rail-ways; up and down which, by the aid of a rope passing over a wheel at the head of the plane, his boats alternately passed, upon a cradle with four wheels, over which his boats were floated at each extremity of the fall. The loaded boat (the trade being a descending one,) drew up an empty one; for drawing the boats out of the upper canal on to the ridge, terminating the descending plane, he used a horse-gin. A few boats only were thus passed, by way of trial, before the works were suspended, and Mr. Dukart's death happening soon after, all of them were laid aside, and since that period a rail-way has been substituted instead of the canals and inclined planes.

Mr. Edmund Leach contrived an inclined plane in the year 1774, five of which he recommended to be used on the *Bude and Launceston* canal, and two of them on the *Liskeard* canal, (see his *Treatise on Inland Navigation*;) he also presented a model of his inclined planes and apparatus, to the Society of Arts, in whose repository, in the Adelphi, it may be seen by any person. This contrivance consisted of a double inclined plane furnished with rollers, from the bottom of the upper canal upwards to a ridge or cross beam, then of a short platform or level part, from which the same kind of double inclined plane, except that these were without rollers, descended into the lower canal for a considerable depth. On each of these inclined planes, a cradle or frame for receiving the boat upon rollers in an horizontal position was placed; and under this cradle was fixed a large water-tight chest or caisson, with a valve in its bottom and an air-hole at top, so that when the cradle and chest were let down into the lower canal the chest filled itself with water, to act as a counterpoise, and regulate the motion. These chests were of such a form, that when the cradles on the tops were in an horizontal position, the sides of the chests adapted themselves to the inclination of the planes, and they had several rollers fixed in their sides to lessen the friction in moving up and down the planes: to the upper corner of this chest a strong frame was hung with hinges like a door; this frame had rollers fixed on both sides of it, and was so contrived, that when the chest and cradle were ascending the plane with a boat upon them, this frame rested on the inclined plane, and prevented by its rollers any friction from the head of the boat against the plane; when the boat had arrived at the top of the plane, this moveable door fell into an horizontal position, and just covered the platform above-mentioned, when the boat was at liberty to be moved forwards on the rollers of the cradle and door, by means of a rope and capstan, to the cross beam, and from thence it could by the same means be lowered easily down upon the rollers of the upper plane into the upper canal. The two chests and cradles above described were connected by means of strong ropes, which wound round an horizontal axis fixed in a strong framing above the top of the planes, so that one of the cradles would always be sunk into the lower canal just deep enough for a boat to float on to the cradle, at the same time that the other chest and cradle were at the top of the other plane, and its door lying on the platform as above described. A water-wheel was to be provided, with cog-wheels connecting with

the axis or barrel for the rope, to give motion to the ropes and cradles with their contents, when a sufficient quantity of water had been let into the upper chest by a valve and pipe contrived for the purpose, or out of either of the chests by means of a string attached to their valves, till an equilibrium of the two chests, cradles, and boats upon them were obtained. By this apparatus it was proposed, that in general one boat should be ascending upon one of the planes while another descended on the other; but the caissons were large enough to admit of sufficient water from the upper or lower level being taken into one of the chests, to balance a loaded boat on the other. The captain worked by men was proposed to be used, for dragging boats out of the upper canal over the upper plane and platform on to the cradle in order to descend. Walking-wheels, to be worked by men, were also proposed instead of water-wheels, where the water was very scarce in the upper canal. The canals above-mentioned were never carried into execution, although an act of parliament were obtained for the former, nor have we heard of any of Mr. *Leach's* planes being brought into actual use.

Mr. *William Reynolds*, of Ketley, in Shropshire, was the first who contrived and executed an inclined plane (which was completed in 1788) for the passage of boats and their cargoes, which was found fully to answer, and continued in practical use. Mr. *Thomas Telford* has thus described the same, in *Plymley's* Agricultural Report of Shropshire, p. 291. Mr. Reynolds "having occasion to improve the mode of conveying iron-stone and coals from the neighbourhood of the Oaken-gates to the iron-works at Ketley, these materials lying generally at the distance of about a mile and a half from the iron-works, and at 73 feet above their level, he made a navigable canal," called the *Ketley canal*, "and instead of descending in the usual way, by lock, continued to bring the canal forward to an abrupt part of the bank, the skirts of which terminated on a level with the iron-works. At the top of this bank he built a small lock, and from the bottom of the lock, and down the face of the bank, he constructed an *inclined plane*, with a double iron rail-way. He then erected an upright frame of timber, in which, across the lock, was fixed a large wooden barrel; round this barrel a rope was passed, and was fixed to a moveable frame; this last frame was formed of a size sufficient to receive a canal boat;" these boats were 20 feet in length, 6 feet 4 inches wide, 3 feet 10 inches deep, and each carrying 8 tons; "and the bottom upon which the boat rested was preserved in nearly an horizontal position, by having two large wheels before and two small ones behind, varying as much in the diameters as the inclined plane varied from an horizontal plane. This frame was placed in the lock, the loaded boat was also brought from the upper canal into the lock, the lock-gates were shut, and on the water being drawn from the lock into a side-pond, the boat settled upon the horizontal wooden frame, and as the bottom of the lock was formed with nearly the same declivity as the inclined plane, upon the lower gates being opened, the frame with the boat passed down the iron rail way on the inclined plane into the lower canal, which had been formed on a level with the Ketley iron-works, being a fall of 73 feet. Very little water was required to perform this operation, because the lock was formed of no greater depth than the upper canal, except the addition of such a declivity as was sufficient for the loaded boat to move out of the lock; and in dry seasons, by the assistance of a small steam engine, the whole of the water drawn off from the lock was returned into the upper canal, by means of a short pump. A double rail-way having been laid upon the inclined plane, the loaded boat in passing down brought up another boat, containing a load nearly equal to

one-third part of that which passed down. The velocities of the boats were regulated by a brake acting upon a large wheel, placed upon the axis, on which the ropes connected with the carriage were coiled." It appears that this plane has an inclination of about 22° , except near the extremities, where it diminishes to about $11\frac{1}{2}^\circ$; and that about 400 tons of coals usually descend thereon daily. In 1789 a copper medal, or halfpenny, having a representation of this plane on one side, and of the cast-iron bridge at Coalbrook-dale on the other, was struck, and issued by the Coalbrook-dale company. Since the practicability of inclined planes has been established, by the success of the Ketley plane, but few acts have been passed for new canals, without a clause authorizing the company to erect inclined planes, instead of locks, if they should be found most advisable. Before proceeding to mention the inclined planes of different constructions, which have been since made or proposed, we shall notice the under-ground plane at Walkden Moor, which was completed in October 1797, upon *Bridgewater's* canal, it being so similar to the Ketley plane above described.

The *Duke of Bridgewater*, in the year 1800, caused an account to be presented to the Society of Arts, in the Adelphi, London, of the inclined plane which he had erected and brought into use, under the direction of his agent, Mr. *Benjamin Sothorn*, between two different levels of his tunnels or subterraneous canals from Worsley near Manchester; for which the Society voted his grace their gold medal, and published plans and sections, and an account thereof, in their 18th volume of *Transactions*; to which we refer, only mentioning, that this plane, which is $35\frac{1}{2}$ yards high, and 151 yards long, through an inclining tunnel hewn in the solid rock, at near 60 yards below the surface of the ground, differs from the Ketley plane, in having, upon about 57 yards of the lower end of the plane, a single rail-way only, to or from which the two rail-ways above join by easy curves, to proceed up to the locks by one rail-way, or down by the other. A winch and pinion are provided, to be occasionally worked by two men, into cogs in the large brake wheel, for setting the boats in motion. Rollers are placed between the iron rails, for the slack part of the great ropes to run upon, and for further preventing the wear of these ropes, they are lapped round with a small cord. About 12 tons of coals are let down in each boat, and a boat and cradle on which it runs, weigh about 9 tons more. About 16 minutes is consumed in passing a pair of boats: the boat-cradles are 30 feet long and $7\frac{1}{2}$ feet wide, moving on 4 iron rollers. A small bell gives notice from the bottom to the top of the plane, when the boats are placed on the cradles, and the machine ready to work. The water of the locks is let down by a paddle, through a perpendicular shaft, to the middle canal, and acts as a water-bellows to force fresh air down into the extensive tunnels and works that are on the lower level. The upper gates of the locks turn in hollow grooves like a common lock, but the lower gates draw up in grooves, by means of windlasses, to let the boats pass out or in when the water is let off.

Mr. *William Reynolds* has the honour of introducing another sort of inclined planes, on the *Shropshire* canal, where there are three planes in use of 120, 126, and 207 feet rises! The act for this canal passed in 1788, and it was completed, under the direction of Mr. *Henry Williams*, as resident engineer, and opened in 1792. These planes are upon the same construction as those at Ketley, except that there are no locks at the top of the descending planes, but the same are continued above the surface of the water in the upper canal, and terminate in a cross beam, from which another plane and rail-way descend into the upper canal: this is for

avoiding the waste of water which locks at the top of the planes occasion. A small steam engine is used for working the axis of the rope barrel, at some distance from which, on the upper side, there is a large pulley or wheel, fixed at a proper height, for the great rope to pass over, to draw the boats up or let them down the long descending plane; another smaller axis and rope barrel are provided, which can, like the larger one, be cast in or out of the engine-geer at pleasure; this last is used for hauling the boats up the short ascending plane, from the upper canal. The engine can also be used to draw empty boats occasionally up the long plane, in case such want to pass, when there are no loaded ones ready to descend, and draw them up, as we have before described. The wheels or rollers under the cradles appear on these planes to be equal in diameter, and not of different sizes, so as to bring the two ends of the boat to a level, as on the *Ketley*; they do not, therefore, appear applicable to very steep planes or to long boats. On the windmill plane, which is 600 yards in length, and 126 feet rise, six boats have been passed down, and six taken up within the hour, the steam-engine and three men only being employed: the boats here are of the same length and breadth as on the *Ketley*, but shallower, so as to carry but five tons; and such boats are said to be passed down these planes for three pence each, and the empty boat taken up gratis. At Wombidge on the *Shrewsbury* canal, Mr. *Thomas Telford* has since erected a plane, 223 yards in length, and 75 feet rise, exactly on the same construction as the above, of which an account, with plans and sections, may be seen in *Plymley's Report*, p. 294.

On the 18th of June, 1793, Mr. *Josua Green* took out a patent for the use of double inclined planes and rail-ways, on which cradles for the boats are to be used, consisting of a frame of wood, and the bottom corded by strong ropes across each other like the common bedsteads, that the boat may not be strained; in order to introduce wheels of four feet diameter for the cradle to move upon, a strong frame is to surround the cradle, and be firmly bolted to it, but leaving an interval sufficient for the four or more wheels to move between it and the cradle, by which the axles can be fixed to the wheels, and work in gudgeons at each end, with less friction than common wheels or rollers. To his brake-wheel handspokes are adapted, for men to assist in setting the machine in motion, instead of a winch as before described on *Bridge-water's*; the ropes are to be capable of adjusting to the proper length as they stretch or contract, by a screw or otherwise. A third inclined plane is directed to be made, for the purpose of carrying a counter weight or vessel, whose rope is to pass over another axis with a brake and handspoke wheel, for hauling the cradles and boats out of the upper level to the ridge or cross beam, or to ease them down into the same. He recommends spare vessels laden with water to be in readiness to pass up or down the opposite plane, as a counterpoise to any single loaded boat that may arrive at the plane. Also that single planes, and with less inclination, may in some instances be adopted. See *Repertory*, vol. v. p. 11.

Earl Stanhope, in the year 1793, in recommending the *Bude and Hatherleigh* canal, proposed, between the different pounds or water-levels of the intended canal, to have iron rail-roads of gradual and easy ascent, on which boats of two tons were to be used, suspended between a pair of wheels of about 6 feet diameter, and to be drawn up or let down the same by a horse, in order to be launched in the upper or lower water-level or canal.

On the 8th of May, 1794, Mr. *Robert Fulton* obtained a patent for the use of a double inclined plane, whereon

cradles having cisterns or caissons under them, no ways different from Mr. *Leach's* above described, except that the boats were in some cases to be taken on to the cradles *side-ways* instead of length-ways; this was proposed to be accomplished by short inclined planes, on which the boats, upon wheeled carriages, were to be dragged out of the upper and lower canals by means of ropes working on the axles of water-wheels; a brake is to be used for regulating the motion of the boats and cisterns, when brought nearly to an equilibrium by the valves; brace-blocks, or pulleys, to be used for shortening or lengthening the large ropes when necessary. See *Repertory*, vol. vii. p. 222.

Mr. *William Chapman*, at page 85, of his *Observations*, which were written principally in answer to Mr. *Fulton's* treatise, suggests this *side-way* motion of boats on inclined planes, as before-mentioned, not knowing, as we apprehend, of Mr. *Fulton's* patent above-mentioned, because it was not published till 1797; and it is indeed singular, that Mr. *F.* should, in 1795, have written 144 quarto pages on the subject of canals, and not once have given a hint of his having taken out a patent in the year before for some of the principles therein explained, and so highly recommended; nor does his long letter in the *Star Newspaper* of the 30th of July 1795, announcing this work being in the printer's hands, make the least reference to his patent. The Board of Agriculture must, we are confident, have been equally in the dark, in March 1796, or they would not have given Mr. *R.* the opportunity of puffing into notice, a subject wherein he was a patentee through their means. We beg here to remark, that our duty, in treating this part of our subject, seems to require the mention of all the inventions and methods which have come to our knowledge; and though we should have more pleasure in making known the inventions of those who lay the same at once open to the community, yet, as all of these will be so in a few years, we have not thought it right to exclude or be less particular in the mention of, inventions or contrivances so circumstanced: but to give the dates of such patents wherever we could, that their termination (at the end of 14 years) may be known.

Mr. *Robert Fulton*, in his 4to. work, entitled a "Treatise on the improvement of Canal Navigation," published in London in 1796, with many plates, has proposed the use of narrow canals and inclined planes, on which small and shallow rectangular boats are to be used, having low wheels, or rather trucks fixed underneath their bottoms; he proposes to have on his double inclined planes, an endless chain passing up the track of one plane and down the other, round or over wheels that are of the proper size and fixed in proper places and directions at top and bottom of the planes to suit the swag or curvature of the leading chain; these are made to revolve at pleasure, with power sufficient to drag a loaded boat up one of the planes, (by means of a short double chain belonging to the boat which is to be hooked into, and will at the proper time discharge itself from the leading chain), by means of toothed gear attached to the upper wheel, on which there are stubs to prevent the chain from slipping; which connect with a water-tub descending in a perpendicular shaft, discharging itself at bottom by means of a valve, and returning again to the top, when cast out of gear, by means of its counter weight, balance-chains, and fly, ready to be again charged with water from the upper canal. The motion of the whole is regulated by a pair of fanners or an expanding fly; a smaller axle and cog-wheel are provided, working into the tub-shaft gear, when necessary to draw the boats up a short plane that descends into the upper canal, on to a bridge or

curving top which unites the two planes, a stop being provided to retain the boat in its proper position, while this last chain is discharged, and the boat-chains are hooked into the leading chains as before mentioned. When a descending boat happens ready to draw another up, or a single one requires to be let down, the tub gear is to be cast off after the boat has been dragged on to the bridge thereby, and the fanners are to be trusted to for easing it down. Mr. *Chapman*, who reviews this system, justly objects to the smallness of the boat-wheels, and recommends that larger ones should be used in a water tight case or groove in the floor of the boat. Owing to the endless chain, Mr. *Fulton* says, that during part of the descent of a boat, the power thereby acquired may draw another boat out of the upper canal on to the bridge; and a boat may in some cases be kept ready in that situation to begin the work; or, he proposes a common windlass tooth and pinion to be used for that purpose. For protecting delicate goods in his boats, he proposes a frame above the boat for supporting the leading chains; and for transferring light timber that is too long for his boats, he proposes rafts to be made with a carriage under them, having wheels like those of his boats, by which these rafts are to be conveyed on the inclined planes. A totally descending trade will not require the tub-shaft, tub or its gear; and the same may be added without interrupting the trade, when at any future time it shall become an alternate one.

Mr. *Fulton* next describes (page 71.) his single inclined plane for great heights; here, his wheel-boats are to ascend and descend on the same rail-way on his plane; the leading chain winds round a barrel or drum, that can, by means of gear that casts in and out, be moved with two different powers and velocities, by a water-tub working another barrel at the head of an upright shaft as before described; or the tub-shaft gear can be entirely cast off, for the tub to ascend, or for a boat to descend on the long plane, regulated by a brake or fanner as before mentioned. Mr. *Fulton* proposes his leading-chain, wheel or barrel, to be so placed over the bridge between the upper and lower planes, and with a roll or small drum below it, that the leading chain hooked to one end of the boat may drag it out of the upper canal on to the bridge, and lower it down from thence without unhooking, and the same in ascending. Mr. *Fulton* (at page 76.) proposes for smaller rises, instead of a tub-shaft, tub or its gear, to erect an overshot water-wheel, to be supplied from the upper level, with proper gear, and a drum for one end of a chain to wind round, the other, after passing over two pulleys at the head of a plane, (one pulley would answer better, by placing the water-wheel or its drum oblique to suit the same) to be hooked to the stern of the last of three or more boats that are to ascend, each of the boats before it being in like manner hooked by their own chains to the leading chain, according to the weight of the boats, and the power of the water-wheel; when water is let on to the wheel, these are to be dragged up, and discharge themselves one by one, and slide down into the upper canal; boats are to be dragged up, single or more than one, out of the upper canal on to the bridge, and when they begin to preponderate towards the descending plane, the water is to be stopped from the wheel, which is to be allowed to turn backwards, and act as a fly or regulator to the velocity of the boats in their descent. The water-wheel will not often admit of being supplied from the lower level, as Mr. *Fulton* has suggested, on account of the great expence or the impracticability of a drain or fough to discharge its water; the same difficulties, as Mr. *Chapman* has observed, attend several of the tub-shafts which Mr. *Fulton* has proposed, for the perpendicular lift of boats from one level of a canal to another, of which we shall treat hereafter. At page 37, and

fig. D, in his 5th plate, Mr. *Fulton* has recommended his wheel-boats, to be used, on a single ascending plane to a coal-pit mouth, to be drawn up the same by a chain winding on a drum, worked by the mine-engine, and lowered down the same by means of a brake attached to the drum.

On the 2d of August 1796, Mr. *John Luke* took out a patent for an inclined plane, on which boats in a cradle are to be drawn up, by the descent of a water-tun on another plane, assisted by a water-wheel in certain parts of its motion, or in scarcity of water, by a hand winch. See *Monthly Magazine*, vol. ii. page 651.

Mr. *William Chapman* recommends an improved kind of inclined plane in his *Observations*, &c. of which he has given an account at page 96., "by making the descending and ascending way continuous, like Mr. *Fulton's*; and having a lock at the head of the descending way, long enough to contain a separate carriage for three or four boats (or so many as form what has been called a conjoined boat). These boats, on descending, would draw another gang light, or half loaded upwards, over the top of the ridge, no lock being requisite on that side. The chief objections to this, lie in the vast weight of a gang of boats, which, in a steep angle of descent, would require a very heavy rope, and in the difficulty of returning the carriages to their proper place. The latter may be got over by keeping the two ways at a little distance, and joining them above and below by a semi-circular rail-way for the carriages; coupled to each other (in such a way as to suit the different boats that are to rest upon them, and yet admit of the necessary extension, when the boat came over the concave part of the inclined plane, which may be affected by a worm spring) to run along under water, after they have parted with their vessels. Both in this and the method last described, the water contained in the lock may be drawn off into a reservoir, at the head of the inclined plane; in this reservoir, or a pond communicating with it, may be fixed a broad underhot water-wheel between the two rail-ways, to retard the motion of the descending boats and throw back the water. This wheel may run in a close case, and be divided round its periphery by different shroud boards, forming so many wheels that one or more portions of its width may be employed at the same time in throwing up water according to the necessity of the case, to be determined by the velocity of the descending boats, which by means of a centrifugal regulator" (the flying-balls or governor used in Bolton's engines, windmills, and other machines,) "will open one or more of the petcocks to let water below the wheel, or shut them all as occasion may require. The reservoir under the wheel should of course never be exhausted, but when drawn down to a certain extent should by a floating weight or any other method let in water from the head canal. These means will answer for a descending trade, and if the ascending trade be more than the other can draw up and water be deficient, recourse may be had to a steam-engine."

We have thought, that a different kind of lock at the top of an inclined plane might be used with advantage, composed of a rectangular box, water-tight, except one end, which should be open, and having wheels under it of different heights, so as to support it upon the plane in an horizontal position, its size being just sufficient for a boat to float into it. The end of the upper canal should terminate in a single lock-gate, the outside border or edges of which should be leathered, or covered with list; so that when the carriage or cradle above described is drawn up to the top of the plane, its open end should fix itself against the lock-gate opening, in a water-tight manner, by means of wedges or screws prepared for the purpose of confining it; a small shuttle in the lock-gate might then be opened to admit

water to fill the cradle, making it act as the chamber of a lock; the lock-gate being opened, a boat might enter the cradle, from which it would expel great part of the water into the upper canal again, if the boat and cradle were nicely adapted to each other; the lock-gate and shuttle should be again shut, when the water might be drawn off into a cistern, (to be returned if necessary by a water-wheel or any of the methods before mentioned), the cradle be unfastened from the lock, and be let down the plane by any of the regulators before proposed. For passing the boat out of this cradle at the bottom of the plane, the back or other end of the cradle might open, or, perhaps a better method would be to continue the plane deep enough into the lower canal, that the cradle, which should in this case be heavy enough to sink in water, might descend low enough for the boat to float out or in, over its end; side rails should, in this case, stand up from the cradle, to shew its place when under water, and for guiding and fixing the boat over it, with liberty to sink into the cradle, as it is drawn up the plane to the surface of the water.

Mr. *Chapman* informs us (page 7.), that for avoiding the friction of the gudgeons of rollers, when charged with the weight of a loaded boat on an inclined plane, *Earl Stanhope* has proposed, that rollers between the boat's bottom and a smooth plane should be used, moving or rolling with the boat, for half the boat's length; the rollers then to return to their places by means of weights acting over pulleys, and connected by a chain to the ends of each roller. Mr. *Fulton*, he says, proposes to use moving rollers, attached to, or going under and through the cradle that contains the boat, the gudgeons at the ends of the several rollers being passed through the links of an endless chain or collar, by which the rollers are returned in a cavity under the boat, that is resting in the cradle; this endless chain of moveable rollers for lessening of friction, appears to be claimed as part of *A. G. Echard's* patent of the 31st of January, 1795, for various machinery: see *Repertory*, vol. ii. p. 365.

The principles of setting out canals, where inclined planes are to be used, are similar to those we have explained, in recommending several locks to be brought together to form a set of such, or a considerable fall in one place; it will, however, be necessary, in determining the place for an inclined plane, to choose ground which slopes as regularly as possible between the intended upper and lower levels; if any part of the ground for the intended plane is springy and disposed to slip, the springs must be cut off by effectual and durable under-drains. It will be better so to contrive the plane, if practicable, that little, if any, filling up of hollows shall be necessary in forming the plane, to avoid new made ground, which on a considerable declivity would perhaps slip, after heavy rains had saturated it with water; the foundations for the stones or bearers must also be carried through such new made ground, and into the firm-fluff. The fluff which is removed in forming an inclined plane, should be carefully levelled, or disposed of in holes, so as not to form spoil-banks, and be covered with the top soil previously taken from those places. In case a perpendicular shaft and fough thereto is wanted at the head of the plane, the knowledge of the *strata*, or matter which compose the hill, may be of considerable importance, in determining the best place for the mouth of the fough; which may not always be the nearest point at the proper level, to the intended shaft, if the *strata* or measures of the hill are various and dip considerably. The plane being formed of a sufficient width on the ground, a strong framing of timber braced across may be used, if good and durable hewn stone is not in plenty, fixed firmly down to a sufficient number of piles drove into the ground, the interstices between the framing

being filled with good rubble stone, or gravel rammed very tight down. On these frames two or four files or rails of sound oak, according as the plane is to be single or double, should be laid parallel and at the proper distances from each other, and firmly bolted down; and on these the slips or ribs of iron are to be evenly and smoothly fixed, for the wheels of the boat, or boat-cradle to run upon, and upon which they are to be confined from getting off sideways, by a rib standing up for that purpose, either upon the wheels or on the rails. If good stone is in plenty, it will be proper to cover the whole of the plane with ashler or well jointed stones, taking care that the courses across the plane at proper intervals are formed of large stones let some distance into and firmly bedded in the ground; and to these the cast-iron rails (that are used on good and durable planes) may be fastened by pins cast into a hole with lead. Or, if wooden rails are to be used instead of cast-iron ones, strong sleepers of wood should be worked into the paving of the plane at proper intervals, on which to bolt and fasten down the rails. Care should be taken, in all works of this kind, where large or hewn stones are used, to let no part of the mortices or holes which are cut in such stones remain open or unfilled with lead or cement, to prevent the rain filling them with water, which would in winter time expand with the frost, and in most instances split the stone. It is unnecessary for us to point out to experienced engineers, the great care and precaution which ought to be used in works of this nature, to make every thing substantial and more than sufficient to sustain the weight or strain to which it will be subjected, and which ought in most cases, particularly the moving parts, to be previously calculated, and before the apparatus is put together for actual use, every rope, chain, framing, wheel, &c. &c. should be subjected to a greater strain than can occur in practice, to avoid the unpleasant, and perhaps fatal accidents, which might otherwise happen, by which a prejudice might at the onset be excited against the scheme, so powerful as to cause it to be laid aside without proper trial. It would much exceed our limits to enter fully into this subject, we shall therefore proceed to those other contrivances for overcoming ascent on canals, where boats have been lifted out of the water, or proposed to be, by a perpendicular ascent; after which, there will still remain to describe those methods which require the shifting of the cargoes of boats into other boats, or to rail-way waggons, &c.; first mentioning that on the *Shrewsbury* canal, an inclined plane is used for passing the boats over part of the ascent, while locks are used for the other parts; and Mr. *William Chapman*, at pages 54 and 99 of his *Observations*, &c. recommends whenever coals in large quantities, lime, lime-stone, or other minerals, are to be conveyed along canals, or are brought in by branch canals on a small scale, there being a scarcity of water which reservoirs cannot remedy, where it can be done in setting out the canal, in addition to the locks, to overlap the levels in a steep place, and communicate them by an inclined plane for boats (or a double rail-way for tram-waggons) leaving the lock communication to answer all the general purposes of commerce. The same author observes, that the portage of articles from one level to another, and carriage of the boat itself is still practised in various parts of North America, as the falls of the Mohawk, from the Mohawk to Wood Creek, at the falls of Orandaga, &c.; also at several places called Tarbets, in the Highlands of Scotland, as in Cantyre, Loch Lomond, Arrachar and Long, Jura, &c. Among the principal inclined planes for boats, are those of Hay, Windmill-hill, and Wrockardine-wood on the *Shrewsbury* canal, Walkden Moor on *Bridgewater's*, Ketley on the *Ketley*, Wormbridge on the *Shrewsbury*, &c.

On the 8th of May, 1794, Mr. *Robert Fulton* took out a

patent, as before-mentioned, in which he describes (see *Repository*, vol. vii. p. 227.) either a rectangular upright notch in the steep face of a hill, to the top and bottom of which the two levels of a canal are brought, or a large perpendicular shaft and tunnel at the bottom for the lower canal, through which notch or shaft boats are to be drawn up or let down, in a pair of water-tight cradles, suspended at the two ends of strong ropes of chains, that are to pass over pulleys fixed above the top of the shaft, and connecting with a brake-lever or wheel, to regulate the descent of a boat in one cradle, and ascent of another in the other, after they have been brought to an equilibrium by the letting out or in of water by proper valves. The boats are to be drawn into and out of the cradles, by short inclined planes, in the upper and lower canal, on which the boats on wheeled carriages are to be drawn by ropes winding on the axis of water-wheels, to be turned by water let out of the upper canal thereon; brace-blocks are to be used for adjusting the length of the great rope, and capstans may be used instead of water-wheels, for passing the boats on and off the cradles. Mr. *Fulton*, in plates 11 and 12 of his "Treatise on Canal Navigation," and his descriptions thereof (pages 97 and 100) has more fully described this method; and proposes for a descending trade, that the full boats should draw up the empty ones, and instead of inclined planes for getting the boats on to the cradles, a cage of iron should be used, into which the boats on the lower canal can be floated; and for discharging them into the upper canal, he proposes two lock-carriages, or large water-tight boxes, open at one end, moving on iron rail-ways, and which can be advanced by racks and pinions over the shafts, while the boat is suspended high enough to clear its bottom; the open end of this lock-carriage is made to fit, and be retained against the frame of a lock-gate at the end of the upper canal, (as in Dr. *Anderson's* and *Fussell's* methods, and the water-tight cradle which we have lately mentioned), when the water being admitted by a valve, to float the boat in the lock-carriage, to the level of the upper canal, the lock or draw-gate thereof is to be opened, and the boat floated out of the cage to proceed on the upper canal; to the pulleys or drum-wheel over which the chains act, a fly or fanners is proposed to be connected to regulate the motion; as also an axis with cranks to work pumps, by which the water that is drawn off again from the lock-carriage into a side reservoir may be pumped up again into the upper canal, that no water may be lost. For an alternate trade, to which it may be at first adapted, or the necessary parts applied afterwards, an additional shaft must be sunk, in which a water-tub is to be suspended, instead of another cage and boat, as a preponderating weight; this is to be filled out of the water reserved in a cistern that is drawn out of the sliding lock-carriage.

Mr. *Robert Fulton* (see his "Observations," p. 94. and plates 9 and 10.), particularly describes a species of Cranes, by which boats are intended to be drawn up, in an iron cage, through an upright notch or shaft, and by the motion of the jibs, are to be moved over the upper canal and lowered down to float thereon, or the reverse in descending; for this purpose a perpendicular notch or shaft for the boats, and another for a water-tub, as a counter-acting and motive force, is to be provided; a reservoir is to be formed by the side of, and about 8 feet from the bottom of the tub-shaft, into which the water discharged from the tub, when at top, can be conveyed by a proper valve and spout; provision is to be made, by valves and spouts, for filling the tub from the upper or lower level of the canal, as occasion may require; and a valve is to be provided, opening by a pin in its bottom, for discharging the water when it rests on the bottom of the tub-shaft; over the tub-shaft a drum is to be fixed, for the tub-chains

and crane-chains to wind round, and to this drum a fly or fanner is to connect by toothed wheels and axles, to regulate the velocity of the motion. The crane-chains are to be double, and proceed to two separate jibs fixed on centres, at proper distances from each other, having the ends of their jibs connected by a coupling-rod of the same length, by which they will always move parallel, and suit the distance of the hooks on the top of the iron boat-cage. For raising a boat out of the upper canal, the same being floated on to the cage suspended from the cranes or jibs, and the water-tub (to which balance-chains are to be adapted) being near the bottom, water is to be drawn, by a valve and spout, out of the reservoir into the tub, till it preponderates and draws the cage and boat out of the upper pound; the jib is then to be moved over the boat-shaft, and the water emptied from the tub by suffering it to descend a little farther and strike the bottom, when the boat will be lowered easily, by means of the fly, to the lower canal, where it can be floated out of the cage; and the reverse on ascending. If water is very scarce in the upper canal, and a sough or tunnel can readily be driven, for emptying the tub-shaft, the same may be made deep enough to draw water from the lower instead of the upper canal, for the preponderating power. We have not heard that any of these perpendicular lifts for boats have been executed, we shall therefore proceed to the other kinds of cranes and perpendicular lifts for the cargoes of boats.

Mr. *Bridge*, of Tewksbury, about the year 1759, contrived, for the navigation on *Stroudwater* river, a kind of cranes, with double jibs, that could be either used singly or together, and act as a balance to each other; these were erected on a strong walled bank, that separated the upper and lower levels of the river at the several mills. The boats to be used on each different level, or mill-stream and dam, were all of one size, and made exactly to suit and contain a certain number of strong wooden boxes, without any lost space. The goods or lading of the boats were placed in these boxes, and when they arrived at the first crane, one end of the chain thereof was hooked to a box, while the other was hooked to a similar box of goods in the other level, and by a peculiar structure of the crane, worked by two men at windlasses, both boxes were drawn up and suspended, somewhat higher than the bank of the upper canal, when the jibs were turned half round, and the boxes of goods were lowered down and replaced each other in the boats; the same operation was repeated with each of the remaining boxes, when each boat was ready to proceed with its new lading upon its own level to the next cranes. It can hardly be necessary to add, that the expence and delay of this method caused it to be soon laid aside.

Mr. *Edmund Leach*, in his treatise before quoted, proposes boats to be unladen and laden with boxes of goods as above, but to work the cranes by water-wheels, or by wheels for men to walk in.

The duke of *Bridgewater's* tunnel from his canal into the coal-works at *Worsley*, after it had proceeded for a great way straight into the hill, came at a great depth to be under a small brook or constant stream of water, by the side of which a large water-shaft was sunk, and a drum and large brake-wheel erected over it, of sufficient size that a man who stands before the lever thereof has his two hands at liberty to pull the lines which connect with the valves, and give signals to those below, while by lunging, or stepping forwards, with his breast against the lever, he can in an instant stop the machinery in any part of its motion, or regulate the same at pleasure. There are two water tubs, which are very large and have a valve and pin to empty themselves quickly when they arrive at the bottom; they are suspended by large ropes

or cables from the drum, while other large ropes descend therefrom through another, or coal-shaft, by the side of the middle or principal tunnel, into and over the navigable tunnel, which there is at, we believe, 60 yards lower level. On this lowest canal boats are used, similar in their dimensions to those above, and containing boxes, which being filled with coals at the several terminations of this canal, in the seams of coals; the boats are pushed along by means of rings that are fixed all along the roof of the tunnel, at the proper height for a man, who walks on the top of the coals, to lay hold of, and shove the boat along by. The boat being arrived under the coal-shaft, and one of the water-tubs being at the top of its shaft, the coal-rope answering thereto is hooked on to the box of coals, and the descent of the water-tub, immediately on the ringing of a bell, draws up the same to the level of the principal canal, where being drawn aside over an empty boat, it is lowered into the same by a slight reversion of the motion of the machine; when the interval of emptying the tub at the bottom by its valve, gives time for hooking another box to the other rope which is at the bottom, when the other water tub is filled, and the machine suffered to move, by the man who leans against the brake. This very complete and economic machine was contrived and erected by Mr. James Brindley, and it is so constructed, that when coals are not drawing, the alternate descent of the water-tubs work some very large pumps, which are sufficient to lift all the mine-water of the lower level into the middle canal and keep the lower canal always at the proper height for navigation.

The same tunnel of *Bridgewater's* canal being continued a great way further into Worsley hill, till under Walkden moor, another subterraneous canal or tunnel there begins, at 35½ yards higher level, this last being near 60 yards from the surface; from the surface two shafts were sunk, one terminating in and over the upper tunnel or canal, and the other in and over the middle or principal canal; there is another canal still lower, which we have been last speaking of, after passing close by the canal above: between these shafts a large drum was erected on the surface, with a brake wheel and a pair of strong ropes. Two boats being arrived at the shafts on the upper canal, one of them loaded with boxes of lime-stone, that was wanted at the surface, and another with boxes of coals intended to be transferred into an empty boat in the middle canal; the ends of the two ropes were fastened to a box of coals and a box of lime-stone, when the superior size and weight of the coal-boxes drew the lime-stone to the surface, to be there landed and deposited, at the same time that the box of coals was deposited in the lower boat, ready to proceed on the canal to Manchester or other places. This method was in 1797 superseded by an inclined-plane for letting down the boats laden with coals, from the higher to the middle level, and returning the empty boats and boxes, as we have before-mentioned. At Brierly-hill, near Coalbrookdale, the extremity of a branch of the *Shropshire* canal, great quantities of coal and iron in crates made of iron were let down one of two shafts, which connected with the termination of the canal above and the ends of a rail-way in a tunnel below, from which lime-stone in similar crates was drawn up the other shaft to be placed in the boat; a large barrel and brake-wheel were fixed between the tops of the shafts, and cranes with jibs, by which the crates could be raised and moved from the boat over the shaft, or the reverse; these shafts, which were 120 feet deep, were not found to answer, in point of expence, so well as inclined planes, and Mr. Telford informs us (*Plymley's Report*, p. 296 and 307.) that inclined planes have been substituted, on which crates of coal, or iron pigs, or goods, descend and draw up other crates

containing lime-stone, for the use of the iron-works above, by means of ropes, a drum, and brake-wheel, with a much less portion of manual labour, and more expedition, than was done by the shafts above-mentioned. Near Lillistall lime-works, on *Donnington Wood* canal, similar shafts were once used, but are now superseded by an inclined plane. At Coombe-hay, on the *Somersetshire Coal* canal, after the trial of Mr. Weldon's diving caisson, inclined planes for descending boxes of coals were erected, and used for some years; but the delay and expence were found so great, that the company effected the purchase of some mills, and under a new act of parliament, erected 22 locks in place of these inclined planes. Having finished with the different kinds of inclined planes, and other ways of procuring the ascent of boats or their cargoes, we proceed to those which are used for overcoming the principal or sudden ascents on rail-ways or tram-roads; whereon waggons or trams are used for the conveyance of goods, the same being drawn on the level parts or easy ascents or descents by a horse, as we shall describe shortly.

Mr. John Buddle, in the *General Magazine* for 1764, page 285, has given a view and description of the coal-waggon which had been then long in use on the wooden rail-ways in the neighbourhood of Newcastle upon Tyne. This waggon moved on four wheels of cast-iron, or of wood with iron rims, having an edge standing up on the rim of each wheel, in order to guide and keep them upon the wooden rails. The waggon is in shape of an inverted prismoid, having a door or false bottom hung with hinges and fastened by a hasp, that can be let go to let out the coals when the waggon has arrived on the staith, and over the spout which is to convey the coals into the ships or keels, or into a heap below as a store; obliquely over one of the hind wheels a strong crooked lever of wood is fixed and suspended, by a strap when not in action; this lever, called a convoy, is intended to act as a brake, by being let down upon the wheel when the waggon is descending down an inclined-plane, or steep part of the rail-way called a run; and on these occasions the horse is unharnessed from the front of the waggon and tied behind, and the waggon-man mounts altride on the hinder end of the convoy, the fore-end being confined closely in a staple in the side of a waggon; and, by means of a rest that there is for his feet at the tail of the waggon, he applies just so much of his weight upon the convoy as will either stop the waggon or give it the proper velocity in every part of its descent down the hill or run: see the *Agricultural Magazine*, vol. iii. p. 241. In the year 1783, we remember seeing an inclined plane or waggon-way as above described, on which the coal waggons descended down the hill from Wibsey-slack to the town of Bradford, which is on a branch of the *Leeds and Liverpool* canal, their velocity being regulated by convoys as above. But some waggons which we have seen, had the convoy fixed to a moveable joint at the front of the waggon, and had a large block of wood thereon, which, when the convoy was let down, wedged in between the fore and hind wheels, and acted most securely as a brake for stopping or regulating the velocity of descent. The empty waggons were drawn up the hill again to the coal-pits by a horse.

An inclined plane for waggons, was erected some years ago by Mr. Barnes, a coal viewer at Bywell, near the Tyne river, of which a description is given in the *Agricultural Magazine*, vol. iii. p. 367, as follows: "It is a very ingenious, yet simple combination of machinery, for the purpose of regulating the conveyance of waggons laden with coals down an inclined plane, and for bringing the empty ones back again, by the same power that resisted its impetus in the descent. The length of the rail-way in which the wag-

gons run is about 864 yards, which distance it descends in two minutes and an half, and re-ascends in the same space of time; so that the loaded waggon can be let down with ease and safety, the coal discharged and the empty waggon returned to the pit within the compass of seven minutes. The impelling and resisting power of motion are derived from a plummet of $16\frac{1}{2}$ cwt., which the waggon in descending and ascending alternately raises and lowers to the depth of 144 yards. The rope, by which the waggon is impelled and accelerated, winds round the axis of a large wheel in a nich or groove in the middle, which gives the rope only space to coil round upon itself, and thereby guards against all possibility of entanglement. Near to the axis of the large coiling-wheel, there is an oblique indention (a range of teeth or cogs) of cast-iron, which corresponds with and works into a similar conformation on the rim of a smaller wheel; round which the plummet-rope is coiled or warped, and it is in consequence thereof moved round, only once in six rotations of the suspending and retracting wheel, which is the same proportion that the elevation of the plummet weight bears to the descent of the waggon; to preserve the rope from injury by dragging on the ground, rollers with iron pivots and brass sockets for it to run upon, are elevated in the middle of the rail-way, but sufficiently low to prove no obstruction to the waggons which pass over them." On shorter inclined planes than the above, horse-gins are sometimes used, for drawing loaded waggons up, and at the same time letting empty waggons down the planes.

The *constructing of Rail-ways*, or, as they are often called, tram, dram, or waggon-roads, require the application of principles so exactly similar, and they are so intimately blended with our several navigable canal and river establishments, that we have before mentioned our idea of the impropriety and difficulty of separating them by deferring the account thereof to a future place in our work: the subject of inclined planes, of which we have last been treating, has required the mention of so much relating to *rail-ways*, that we beg to proceed with and finish that part of our subject, before we resume the subject of bridges, towing-paths, fences, drains, boats, moving boats, &c. which yet remain to be mentioned. From the first opening of the coal-mines on the banks of the Tyne river above Newcastle, until about the year 1680, it appears, that the coals were conveyed in carts and wains, from the mouths of the several pits, to the keels or vessels, that conveyed them to the sides of the ships lying below the bridge. As this kind of fuel came to be substituted for wood in London and other cities, and towns on the south and eastern parts of the island, the consumption of Newcastle coals became so considerable, that we are told, that several coal-mines, as the Kinton, Benwell, Jesmond, &c. gave employment to 400 or 500 carts or other carriages each, for conveying the produce of those pits to the water-side: the difficulty and expence of maintaining so many horses, and cost of repairing roads for such considerable traffic, occasioned the introduction, about the period above mentioned, of waggon-roads or wooden rail-ways, on which waggons of a large size, with wheels of a particular form to suit the rails, were used, and which one horse could draw, owing to the regular and easy descent with which the rails were laid. It was not until the year 1738 that this important improvement was introduced at the White-haven collieries on the western coast, and it is truly surprising to observe how slow the introduction of them was in other parts.

Way-leaves or slips of ground were set out and hired on lease, or purchased by the different coal-owners of the several proprietors of lands, lying between their pits and the river, and this, not by the nearest route, but in such a direc-

tion as gave the most easy and regular descent. The inequalities of this slip of ground were levelled as a road, hollows were filled up, and sudden hills lowered, when sleepers or large logs of wood were laid across the same, their tops being all of a regular height; upon these, two rails, generally of beech wood, were laid parallel to each other, their ends abutting close to each other, and were firmly pegged down to the sleepers. The tops of the rails were planed smooth and round; the wheels of the waggons were low and of cast iron, or of solid wood with iron rims, which were not flat on the edge, but hollow to receive and move on the wooden rails; the inside edge of each wheel projecting near two inches, in order to confine the wheels effectually to the rails, and prevent the waggon from being drawn off the road. From all considerable works, there was a main way made for the passage of loaded coal-waggons as above; and another, or bye-way by its side, for the return of the empty waggons. When coal-mines had been worked into deeper ground, and pits or shafts were opened below Tyne-bridge, the rail-ways therefrom were conducted to the top of a stage or wooden building called a staith, on the wharf or key where the ships lay; and the coal-waggons, a description of which we have already given, were either emptied at once through the spouts into the hold of the ship, or deposited in the warehouse below in store for future ships. One indifferent horse could in general draw three tons of coals from the pits to the river side upon these wooden rail-ways; which mode of conveyance became further improved by the introduction of plates of wrought iron nailed on to the rails for the waggon-wheels to run upon. Attempts were made in different parts, to introduce cast-iron instead of wooden rails; but owing to the brittleness of the material, and the great weight of the waggons in use, they did not in general succeed.

About the year 1768, Mr. Richard Lovell Edgeworth contrived a remedy for the principal objection to cast iron rail-roads, in making use of two or three smaller waggons linked together, instead of one large one; a model of three of these he presented to the *Society of Arts* in the Adelphi, London, and was honoured by the premium of their gold medal. In the year 1788, the same gentleman, on some temporary wooden rail-ways for manuring of land, made several experiments, in the presence of different Mechanics, on the application of friction-rollers for diminishing the friction of waggon axles. The rail-ways hitherto constructed were private property, or for the accommodation of particular mines or works, and it was not, we believe, until about the year 1794, that Mr. Samuel Homfray, and others, obtained an act of parliament for constructing an iron dram-road, tram-road, or rail-way, between Cardiff and Merthyr Tydvill in South Wales, that should be free for any persons to use, with drams or trams of the specified construction, on paying certain tonnage or rates per mile to the proprietors. Soon after the year 1797, iron rail-ways began to be constructed as branches to the canals of Shropshire; and, in other parts of England, Mr. Benjamin Outram, an engineer, began to construct the same upon improved principles, of which Dr. Anderson has given an account in his *Recreations*, vol. iv. pages 199 and 473.

On the 25th of June 1799, the house of commons made a standing order for extending to all bills for making any ways or roads, commonly called rail-ways, or dram-roads, all the orders (of May 7, 1794) relating to the introduction of canal bills. One principal difficulty, the provision of water, does not here occur, unless for docks or basons, which are not unfrequently necessary, at the termination of a rail-way, at a river, or existing canal; and, as the owners of streams of water are not under dread of losing the same by the passage

of a rail-way near them, and the same is applicable so much more easily to the uses of the owners and occupiers, than a canal is, less difficulties will attend the obtaining of general powers for making side or collateral branches, at any future period; and of connecting the same with different rivers, canals, or rail-ways, making the parties a compensation in tolls or otherwise, if such connection shall appear to draw off or lessen the trade upon any part of their line of communication, as often happens; and such ought always to be carefully investigated, and liberally estimated by the engineer, and the company be advised to act accordingly.

In surveying a line of country for a rail-way, principles somewhat different from those which apply to a canal, are to be kept in view; in the latter case, exact or dead levels are traced out, and the ease of towing or dragging boats thereon is nearly the same in going one way as in returning the other, whether laden or not, for the ascent or descent of the locks or planes are there overcome by a different power than that applied to towing upon the levels; in a rail-way the case is different, the horse which in going one way draws a very heavy load down a slight descent, has to return again with the empty waggons, or a lighter laden, up the same ascent. It will therefore be necessary, as a preliminary step to setting out a rail-way, to calculate as accurately as possible the quantity of lading which will at the first or any future period be to pass each way upon the line, or on any particular parts of it, because on this will depend, in a great measure, the slope that it ought to have, and consequently the ground which the rail-way line ought to occupy. If it should appear, on an accurate calculation, that the same weight of lading may be expected to pass one way as the other, or that the same will preponderate at some periods one way, and at others the other way, the rail-way must in this case be set out in levels or very nearly so, and the unavoidable ascents and descents must be made by inclined planes, as before mentioned; on which either a greater number of horses must be stationed to draw waggons up, and in letting down, their wheels must some of them be slipped; or loaded descending waggons must draw up the others; the descent of a weight or tub full of water in a shaft must draw up a waggon, or more than one; or, a steam-engine, horse-gin, or walking-wheel, must be used as a moving power, with fly or brake regulators of the motion, as we have before mentioned. If the trade will always preponderate one way, as it generally will in the descent from mines to navigations, and the ground will admit of the same, the regular inclination of the rail-way ought to be such, that a horse can draw the usual lading down with the same ease as it can return with the waggons when emptied, or with a partial lading, in case of there being a small ascending trade. If the slope of the ground shall be found greater than to suit the above calculation, the rail-way ought to be set out for as great lengths together as is practicable, with the proper slope, and then to set out an inclined plane, as before mentioned. It ought to be well considered, where a rail-way or a branch from the same appears likely to have a descending trade at present, whether, at a future period, by extending the same forwards to any town or manufactory, or by other change of circumstances, the ascending trade is likely to be materially increased, in proportion to the descending; because in such case, the line would require to be altered in its slope, and moved to a new place, or it must continue to be worked to a considerable disadvantage by the horses having to travel down the line unemployed, to fetch up a portion of the loaded waggons. It will readily be perceived, that the adoption of the best line, of which the

circumstances of the trade and nature of the ground is susceptible, is a task requiring a degree of skill and patient research, not at all inferior to any thing required in the setting out of a canal, and it can hardly be necessary to point out the necessity of employing the most competent engineer, and allowing him proper time and assistance, in order to get the most eligible line marked out. A rough section of the different routes which appear eligible for a rail-way made by levelling with a spirit level, will be very useful in the first instance; from which, and a view of the ground, the engineer will be able to determine nearly the place and extent of the inclined planes, or steeper parts of the rail-way which will be necessary; these last being always made as short as the nature of the ground and circumstances will admit. These being settled, the line of the intended rail-way must be traced on the ground, beginning at the highest point, and stretching a chain on the ground, one end being held at the point of departure, the other must be turned round upon the face of the descent, until a point marked by this end is found, which is one link (or something more or less, according as the slope is to be) lower than the upper end; the chain being now moved forwards, till the hinder end rests on the point last determined, the other end is to be moved, accompanied by the levelling target, until a new point is found, one link lower than the last, and so on; by which, a line having the regular descent of one link in a chain, will be traced out on the ground, until the place of an intended inclined plane is reached. The stakes which are put in to mark the place of each successive stake will, as in the case formerly mentioned, of setting out a level for a canal, be found very crooked in many places; and it will be necessary for the engineer to stake out a new line, after a most careful view and consideration of the ground, as the approximate line for the centre of the rail-way; which must be without any sudden bends, that would occasion friction of the wheels against the sides or ribs of the rails. Single rail-ways will generally require about four yards wide, and double ones about six yards wide (exclusive of the necessary space for drains and fences), and this width will require to be levelled like a road or plane: it will therefore be proper so to set out the line, that the quantity of stuff which is to be lowered in one place shall always, with the least distance of throwing or barrowing, make up other places which are too low. Where sudden valleys are to be crossed, it will be necessary to conduct the line, so as to cut into the hill at each side of it, to find the stuff as readily as possible for forming the embankment: it will also be necessary to search carefully for gravel or stones fit for making the road between and under the rails; and if such can be got in the line, it may be a considerable saving of labour and of damage to the land, as well as a source of future advantage to the concern, to cut pretty deeply into such materials, as we have before suggested and explained on the setting out of a canal; which the reader, who wishes to understand this subject, would do well to consult. A line of stakes, exactly at a chain (100 links) apart, should be put into the line last staked out, and drove successively into the ground, beginning with the highest, so that the head of each may be very exactly one link (that being the fall we have assumed) below the level of the last; of course these will either stand above the ground, or be drove in the bottom of a hole, according as the ground wants raising or sinking, and will enable the engineer, on a review of the line, to judge more correctly, or to calculate where necessary, whether the line is set out in the right place to be formed at the least expence of labour, and with the least damage to the land; and when this is

found to be the case, the necessary width of land can be determined on, and the same surveyed and described by the surveyor, for the purposes of depositing the necessary plans with the clerk of the peace and with parliament. The different regular slopes or parts of the rail-way being determined in this manner, the steeper slopes or planes that may be necessary to join them, must next be set out and determined, by taking the whole fall or difference of the levels of the two ends, and dividing the same by the number of chains that the plane is to be long, for obtaining the fall which is to be allowed between each pair of stakes, instead of a link as before assumed. In setting out a single rail-way, it will be necessary, at proper intervals, to allow the width of land proper for a double rail-way, for a short space, in order to form passing-places for the waggons that are coming different ways. As part of the rail-way will in most cases be conducted along the side of a hill, or on side-lying ground, it will be necessary to consider the same in calculating to dispose of the stuff, and for the necessary ditches and drains for intercepting the springs and surface water in every instance, so that the ground of the rail-way may at all times remain dry. The draining, fencing, and bridges, will require to be done on the principles which we shall further on explain respecting canals; and the embankments, culverts, or tunnels, which may be necessary for preserving the proper slope in all places, are also to be done on similar principles to those of canals before treated of. It may be proper here to mention, that Mr. *Robert Fulton*, in his *Treatise* before quoted, pages 82, &c. has suggested and described different kinds of cast iron bridges for passing rail-ways over valleys, either level across, down one slope, and up the other of the valley, or rising obliquely up; in the first and last of which he proposes to avoid any solid platform or top for carrying the horse path, and to tow or drag the waggons over this open rail-way, by an endless rope or chain, passing over a pulley at each end, which can be set in motion by a windlass, a descending weight, or other power. On the approach to a river or yard, where considerable quantities of coals or other minerals are to be discharged, it will be proper to keep the rail-way upon a high level, by embankment, or on arches, or on a stage of timber, that the waggons may be discharged from the top of a staith or stage into ships or boats, or into carts and waggons, without being moved by manual labour. Rivers, brooks, or hollow roads, must be crossed on bridges whose tops are formed to the regular slope of the plane; and where roads cross the intended rail-way, they must either be raised so as to be carried over, or sunk so as to pass under the same; or be made up to the same height; and the rails must, in that part, have ribs of less height and greater strength, and the whole must be so firmly embedded on masonry, that the heaviest carriages, in crossing, cannot damage it: an instance of which may be seen in Wandsworth town street, and at several other places on the *Surry iron rail way*.

A considerable facility is occasioned in the *constructing of Rail-ways*, after the plan of the whole is settled, the act passed, the land purchased, the work set out, and the ground levelled and properly settled, by being able to begin in any part where stone, gravel, and other materials that are wanted are to be most conveniently had, and to work from those places without the heavy expence of common cartage, except for the iron rails or blocks of stone for sleepers, if such are not found upon the line.

We will therefore suppose the work to begin at some point where the line intersects a rubble rock or a bed of good gravel, and the surface of the road is to be covered therewith

for about a foot thick, and the same is to be nicely levelled, and any great or rough and out sized stones should be carefully picked or raked off, that the whole may the sooner settle down and become one compact mass; these large stones may be thrown forward upon the unformed part of the road, to be covered with smaller and better gravel. This covering of rubble or gravel must be nicely raked and levelled and beat or rammed down, to make it as compact and solid as possible. A great quantity of blocks of hard and durable stone must be got in readiness, from 8 to 12 inches thick, and weighing 150 to 200 lb. each; the shape of them is not very material, so that the bottom is flat, to bed firmly and evenly on the gravel, and the top is to be chiselled to a level to receive the ends of the iron rails; in the centre of this flat part a hole must be drilled about $1\frac{1}{2}$ inch diameter, and 6 inches deep. Two flat and straight gauges of iron must be provided with pins riveted into their ends to suit the holes in the stones; the pins on these gauges should be at the exact distance on one of them to suit the length of the iron, generally three feet, and the other to suit the distance of the rails apart or breadth of the road, usually about 4 feet. One of the stones being laid in the proper place for the beginning of one side of the rail-way, and nicely bedded and rammed down upon the gravel, another stone is to be laid at 4 feet distance for the other side of the road, and for bringing them to the exact distance and level, the pins of the breadth-gauge are to be entered into the holes in each stone, and a common or mason's level is to be applied to the top of the gauge; if the stone last laid is found too high or too low, it must be lifted up again, and gravel must be raked out, or more fine and good gravel sprinkled in and rammed down, until the right height is obtained; the stone is then to be laid on again, and brought to its proper place by means of the gauge and level; care is to be taken that the top of the stone is level, so that the flat ends of the gauge bed exactly and evenly on the stone all around the hole; and if this is not the case the chisel must be used to take down any irregularity and produce this bedding of the gauge bar. A third stone is then to be laid on one side and the length-gauge pins entered into the holes, by which the exact and proper distance of the stones will be ascertained, and for trying the truth of this stone as to height, a level is to be used, in which a line is very carefully drawn by the engineer, making the exact angle with the perpendicular line that the rail-way is to make with the horizon; this being applied upon the length-gauge will shew whether the stone last laid requires more gravel under it, or any to be taken out, observing always to level the gravel carefully and to ram it down, and also to ram the stone down upon the gravel, before each ultimate trial of its proper position as to level, its distance measured by the gauge from the other stone, and its range by a line stretched in direction of the intended rail-way. With these precautions the stones are to be successively laid, and gravel of the best quality, and without any large stones, is to be laid in, to fill up the spaces between them; and some on the outside of the stones, the better to secure them in their places; and when a certain length is done, as no mortar or other soft material is used which requires time to dry or set, the work is ready to receive the rails, and will be then immediately fit for use, to carry forward the gravel, stones, and other materials for the work as it proceeds. We have before mentioned that the ground work should be settled; and for this purpose the levelling of the road should be performed early in the winter, and the rains and frost will effectually settle it, by the time the work gets dry enough in the ensuing spring;

before which, the work should be carefully gone over again, to level and fill up any parts which have settled more than was expected and allowed for.

The *cast Iron Rails*, in the earlier use of them, as on the extension of the Caldon branch of the *Trent and Mersey* canal, to Mr. Gilbert's lime-works, 4 miles in length, (which was in use long before 1794,) were fastened down upon longitudinal rails of wood, which lay across several wooden sleepers, embedded in the gravel, as we have described above; these rails were three feet long, and had two holes, at 18 inches apart, to receive the wooden pins which fastened them down, or rather confined them in their places, on the wooden rails: (see *fig. 31, Canals, plate iv.*) at one end there was a triangular projection, and at the other a similar notch which fitted into each other; a rib stood up along one side, to confine the waggon wheels to the track; and opposite the holes, the rail which was about $1\frac{1}{2}$ inch thick and weighed about 42 lb. was made wider to strengthen that part; yet, with this precaution, such rails were very liable to break in two at the pin holes, as well as to loose their connecting triangular piece; the rib also was very liable, by the wheels or other things striking against it, to get broken off near the ends, and the waggons were not confined from running off the road in such places. The rails of the *Surrey Rail-way* are represented in *figs. 32 and 33*, and are, we believe, of the most improved construction; they have their ends resting on separate blocks of stone embedded in the gravel as above described, and, instead of pin-holes through them, each rail has a similar rectangular notch in its end, which, when two of them are laid close together, forms a counter-work-hole for a square and headless spike of iron, that is to fasten the ends of both the rails. These rails consist of a rectangular plate of cast iron, 3 feet 2 inches long, 5 inches broad, and 1 inch thick; a piece of metal about half an inch thick is added in the casting, to increase the thickness at each end for 5 or 6 inches in length, where it is to bear on the stone and receive the spike; a rib is cast on to each edge of the rail, one of them above, and serves to guide and confine the waggon wheels; the other below for adding strength; these ribs which are about three-fourths of an inch thick form by their top the segment of a large circle, being about $3\frac{3}{4}$ inches high in the middle, and about $1\frac{1}{2}$ inch at the ends, by which these ribs are calculated to give the greatest strength to the rail in the middle, where it has no bearing, and to make them not to be easily snapped or broken off, as mentioned of those rails above, whose ribs are of an equal height throughout; small circular projections of metal are cast on to the width of the rail near each end, and the same are carefully bedded upon the stone, for preventing the rail from being overturned laterally, by the action of the wheels against the rib. For crossing of common roads, the rib, (see *fig. 34*.) is made only an inch high throughout, and near an inch thick, and its edges are well rounded off. In these situations, a few rows of pavement, of good square stones, such as the carriage way of the streets of London are now paved with, are kept nearly or quite as high as the ribs of the rails, by which the heaviest waggons, carts, and coaches pass over them almost without any sensible jolt. Crossing-rails are used at every passing-place, or point where waggons are to pass out of one track of rails into another, which are very numerous in the company's yard, by the side of their basin or dock for barges, in order that empty waggons or those loaded may be readily pushed into one of the tracks further off the wharf, to let other full or empty ones advance, on their proper track, to the sides of the barges. *A B C D, fig. 35*, represents one kind of crossing-rails, shewn

in connection with four common rails, parts of which are represented by E, F, G and H; a wedge or tongue of wrought iron, I, is moveable round a pin, and is represented in the figure, as placed against the stub K, so that the track from G to F is clear for one of the wheels of a waggon; and by moving the wedge I till it rests against the stub L, the track from H to E would be clear; before the waggon can pass in the directions above-mentioned, the wedge will often want moving by hand to the proper position, but in going in the opposite direction from E to H, or from F to G, the action of the wheel against the wedge will always move it into the right position; there is a circular guard or stub cast on to the rail behind the joint of the wedge for preventing the wheels from striking directly against the end of the wedge.

The method in which the rails are fastened to the blocks of stone on which they rest, is by an octagonal peg or trunnion of good sound dry oak, fitted to the hole in the stone, so as to drive easily into the same, otherwise its swelling by wet and the driving of the spike might split the stone, this plug of wood is not long enough to reach the bottom of the hole, and is sawed off even with the top of the hole; a hole is then bored through this plug of wood, and an iron spike with a flat point, and a head just fitted to the counter-sunk notch in the ends of two rails, when applied endways together, is drove; by which the rails are sufficiently confined, and yet in case of any wear or settling of the stone, so that the rail gets a little loose, it is capable of moving that small space without breaking out the sides of the pin-hole in the rails. It will be proper, always to drill a small hole from the bottom of the plug-hole, quite through the stone, for the rain water to soak away into the gravel, otherwise the freezing of water in the holes would often burst the stones. Care must be taken from time to time, to keep the tread or surface of the rails clear of dirt or stones, which last would stop the waggon, and perhaps break the rails; and too much pains can hardly be taken by raking and forcing the gravel, for the finish or top of the road, and rolling or ramming of it down, to settle the same into a compact and hard road as soon as possible, having no loose stones, which the horses are always kicking on to the rails, and while this is the case, the man who attends the waggons should always go before his horse, and look carefully to the rails, and remove any stones that may have got upon them. The waggons in most general use on the *Surrey iron Rail-way* weigh, including their loading, about $3\frac{1}{4}$ tons, the wheels are two feet five inches high, of cast iron, with 12 spokes, which get wider as they approach the hub, which is eight inches long to receive a small wrought iron axle; the felloes or rims of the wheels are two inches broad, and nearly as much thick, and the sharp angles are rounded off, so that these wheels are capable of being used without damage on any hard common road; a very principal advantage attending the modern use of rail-ways. The axles of the wheels are fixed at two feet seven inches distance; the bodies of these waggons are seven feet nine inches long, four feet five inches wide, and two feet four inches high; these are used for bringing down chalk from the Surrey hills to make lime, carrying back manures, &c. The founders, and others upon the line, have trucks or waggons of different kinds to suit the nature of their goods; the only apparent limitations being in the width of the wheels and carriage, the length of their axles, and weight of lading.

For the more ready emptying or shooting the contents of the waggons into barges lying in the dock, a strong stage is erected on the wall, which projects over the water, and in

order to turn waggons short round and back them on to this stage, the rail-way passes over a large circular plate of cast iron, which is suspended on a pin beneath its centre; there being a circular ring under its circumference, which moves round freely, with a considerable number of small wheels or rollers, whose axles are fixed therein, (see *figs. 45 and 47, Plate VII.*) upon another circular iron plate firmly fixed below; by this arrangement, it happens, that as soon as the fore and hind wheels of the waggon are advanced on to this circular plate, a very small force applied to the waggon will turn it a quarter round, along with the plate and rails on which it rests: the waggon is then run backwards off the plate, on the stage before mentioned, and its contents are shot into the barge below; it is then returned upon the plate, and the same is turned round until the rails thereon match the track, and the waggon can then move forwards, to make way for another loaded waggon, to be emptied in like manner, or it can be shoved backwards to a crossing-place, as may be required. A ton weight or more in a waggon can easily be shoved along by a man, as he does a wheel-barrow. Rail-way branches are capable of being conducted into every foundery, or other great work near the line, to terminate under their large cranes for hoisting goods, so that heavy articles can be loaded at once on to trucks for the rail-way. The branches of a rail-way admit of being multiplied almost without limit; farmers and others who have but an occasional trade, may have their own waggons to be kept locked, and left for them by the side of the rail-way, one or more at a time, from the gang that is passing along the line. About November 1800, Dr. *Anderfon* recommended, in his *Recreations*, vol. iv. p. 204, the adoption of a double rail-way for heavy carriages between London and Bath; and about March 1802, Mr. *R. L. Edgeworth* recommended, in *Nicholson's Journal*, 8vo. vol. i. p. 221, the experiment to be tried, on one of the great roads, for ten miles or more out of London, of a rail-way with four tracks, one for flow and another for fast travelling carriages going each way, in order to avoid meeting or delay; these he proposes to adapt to chaises and stage coaches, by means of low cradles or platforms, with wheels adapted to the rails, on to which a chaise, coach, or other carriage, could be drawn, and there confined, in order to be drawn along the rail-way; and which cradles the coaches might leave at any desired point, to be drawn on the common road, which he proposes to have by the side of his rail-ways. Dr. *Anderfon*, in the volume above quoted, recommends rail-ways to be made from the docks in the Isle of Dogs, to different points in the environs of London; and he proposes the bodies of these rail-way waggons to be moveable, and to be hoisted off by cranes with their lading in them, and be placed on other, and larger wheels, with shafts adapted to the streets; which, after delivering their lading, would return, perhaps laden with other goods, to the cranes to be replaced on the rail-way wheels. In vol. v. p. 291, of the doctor's work, it is recommended to use waggons on the proposed rail-way with wheels large enough, and of a proper construction, to be used in the street also. Wherever any considerable work is to be done, as in the excavation of the *London-Docks*, it has been found to answer, to lay down temporary rail-ways; and such as admit of being moved as parts of the works become complete. For the use of mines, this facility of removal is often of consequence, as the veins or pits wear out.

Doctor *Anderfon* observes, that 20 tons, in a barge upon a canal, will be drawn with ease by one horse, travelling at the usual rate that waggons move; and that on a rail-way the same horse would, under favourable circumstances, trans-

port the same quantity of goods in a given time: but Mr. *Fulton* says, that five tons to a horse is the average work on rail-ways, descending at the rate of three miles per hour; or one ton, upwards, with the same speed. Mr. *Telford* observes, that on a rail-way well constructed, and laid with a declivity of 55 feet in a mile, one horse will readily take down waggons containing 12 to 15 tons, and bring back the same waggons with four tons in them. Mr. *Joseph Wilkes* in 1799 stated, that a horse of the value of 20*l.* drew down the declivity of an iron road $\frac{1}{8}$ of an inch at a yard, 21 carriages or waggons, laden with coals and timber, weighing 35 tons, overcoming the *vis inertia* repeatedly with ease. The same horse, up this declivity, drew five tons with ease. On another part of the road, where the acclivity was $\frac{1}{4}$ of an inch at a yard, the same horse drew down three tons; but it was necessary to slipper or lock the wheels here, to prevent his being overpowered by the descending weight. On a different rail-way, one horse, value 30*l.* drew 21 waggons of 5 cwt. each, which, with their loading of coals, amounted to 43 tons 8 cwt. down the declivity of $\frac{1}{3}$ of an inch in a yard; and up the same place, he afterwards drew seven tons; the cwt. in all these experiments of Mr. *W.'s* being 120*lb.* In the summer of 1805 a trial was made on the *Surry* rail-way by Mr. *Banks*, wherein a horse, taken indiscriminately out of a team, drew 16 waggons, weighing upwards of 55 tons, for more than six miles along a level or very slightly declining part of the rail-way.

Dr. *Anderfon* has calculated the expence of carrying goods in common waggons, or turnpike roads, a distance of eight miles, at 3*s.* 4*d.* per ton, and of carriage, the same distance, on a rail-way, at 4*d.* per ton, or only a tenth part of the former. *Recreations* iv. 208.

For steep descents, sledges, or slippers of iron, must be provided, similar to those in common use with road-waggons, which can be placed under the wheels of the rail-way waggons, and hooked to the side of the waggon by a short chain, in order to cause the wheel or wheels to slide upon the rails, whereby the tendency to descend may be checked.

Mr. *William Chapman* has, in his *Observations*, p. 42 and 54, recommended the use of waggons, that are to run on to the rail-ways that are to be prepared in the bottom of a flat-bottomed boat, instead of unloading the contents of the waggons into the boat; and when this boat with its waggons has arrived at its destination, the waggons are to be run out upon other rail-ways, to proceed forwards by land if necessary.

Mr. *Carr*, we are told, has introduced in the mines of Shropshire, and other places, a slight kind of iron rail-ways, called train-roads, for the use of very small waggons in their under-ground works.

Mr. *R. L. Edgeworth* has suggested (*Nicholson's Journ.* 8vo. i. 223,) the use of light circulating chains running upon rollers, which are to be put in motion by small steam engines placed at considerable distances; to these chains he proposes carriages to be attached, for dragging them along upon rail-ways instead of using horses. Since steam-engines have been brought into use, to work by the expansive force of steam, and requiring no water for condensation, a successful trial of applying them to moving the trams on a tram-road has been made, viz. in February 1804, on the *Cardiff and Merthyr* rail-way, where 10 tons of iron (long weight) loaded on tram-waggons, with the additional weight of about 70 persons for great part of the way, were drawn for nine miles upon the tram-road, at the rate of near five miles per hour, by the use of one of these steam-engines fixed on its own waggon made by Mr. *Homfray*, (for which engines Mr. *Trevadick* had previously taken out a patent, though it

is perhaps an old invention) no supply of water for the boiler being found necessary in this distance.

The cost of a single rail-way, with crossing-places, for a descending trade, was estimated by Mr. *Fulton*, who wrote in 1795, at about 1600*l.* per mile. Mr. *Wilkes*, in 1799, stated, that the expence of completing a mile of single rail-way, where materials of all descriptions lay convenient, and where the land lies tolerably favourable for the descent, would be about 900*l.* or 1000*l.* fenced, &c. exclusive of bridges, culverts, or any extra expence in deep cutting or high embankments. Dr. *Anderfon* mentions, in 1800, the sum of 1000*l.* per mile as the probable cost of a double rail-way in the most favourable situations, and of very stout ones in the vicinity of London, where labour is dear, not less than 3000*l.* per mile; and Mr. *Wilkes* says, that wherever the quantity of goods to be conveyed on a rail-way, having a descent of not more than $\frac{1}{2}$ an inch in a yard, amounts to two-thirds of downwards, and one-third of upwards loading; it is a doubt, if it will not, in that case, be a cheaper conveyance than by a canal, besides the rail-way being more certain, where dispatch is necessary, on account of frost and dry seasons. Another advantage attending rail-ways is, the greater certainty of the estimates for the same, when made with care and judgment, and the facility with which the whole work may, in general, be contracted for, to be completed at a stated time. The principal rail-ways which have been executed, are the *Cardiff and Merthyr*, the *Caermarthenshire*, the *Sirhowy*, the *Surrey*, and the *Swansey and Oystermouth*; and such branches will be found to the *Abby de la Zouch*, *Cromford*, *Derby*, *Erewash*, *Lancaster*, *Leeds and Liverpool*, *Peak Forest*, *Shropshire*, *Somerset Coal*, *Trent and Mersey*, and several others, to which number almost every day is adding.

The *crossing of Bridges* for crossing canals and navigable rivers, often occasion a very serious part of their whole expence, and this circumstance occasioned the attempt in some of the earlier canals, to substitute paved *fords* in many instances; Mr. *James Brindley* proposed these at first, for some places on the *Trent and Mersey* canal; and on the canal which Mr. *Davis Dukart* constructed to the *Tyrone* collieries in Ireland, these were substituted in place of bridges. Mr. *Fulton* has recommended the general adoption of fords on his small canals, but Mr. *Chapman* observes, that the water in such cases must not exceed two feet nine inches in depth, as otherwise hay, sheaves of corn, &c. in common carts would be liable to get wet in crossing. On the China canals we read, that there are elliptical arches of stone over their canals, the longer axis being vertical, and high enough for the masts of their vessels; these bridges being only intended for foot passengers, and are ascended and descended by steps. On our canals, bridges for foot passengers only are generally constructed of wood, and are mounted by steps, as at *Paddington* on the *Grand Junction*. In all large and important bridges the arches should undoubtedly be so formed that the materials thereof are in equilibrium, independent of the cement that may be used between the stones or bricks; the principles of which arches will be found in our articles *ARCH* and *BRIDGE*; but for the common bridges for crossing of canals, which are wanted in such great numbers, flat semi-elliptical arches have been, in general, adopted, on account of such giving width for the canal and towing-path underneath, without raising the top any unnecessary height, which so enhances the expence of landing up, or forming the slopes to the bridge. From the habits which necessity has in a great measure introduced with canal bridge-makers, of using only the best materials, performing the work with great care, and not striking their centres too soon, such bridges are found to stand tolerably well, although very far removed

from an equilibration figure; yet instances are not wanting on most canals of their settling, and even falling down in some cases. A kind of brick bridges have long since come into almost general use on canals, of which we have given a plan, section, and perspective view. See *CANALS, Plate IV. figs. 40, 41, and 42.* The form of these bridges is well calculated for saving of materials, and giving strength at the same time, the whole of the walls being more or less battering, and the side walls are splaying outwards at their ends, to make the entrance on to the bridge the more easy, by which the side walls are rendered curving inwards in every part. In the building of bridges the utmost care must be taken to sink the foundations down to sound stuff, or to drive piles on which to begin the work; it is a good practice to have wedge like or arching bricks made, on purpose to use after a certain number of courses of key bricks, or those forming the soffits of the arch, and to introduce oblique courses of bricks for the more effectual tying of the work together, as we have mentioned in speaking of tunnels. Large bricks made of the best earth and well burnt, should also be used, placed on edge upon the top of the walls of the bridges, as a coping, unless very good stone is near at hand, the top corners of the coping bricks or stones should be carefully rounded off in the making, in order that the same may present as few angles as possible for the weather or the traffic to catch hold of.

We have before mentioned the care which ought to be taken in every instance, to find stuff with the least possible expence of moving it, for landing up the bridges; from these having, in some instances, been left too steep for the convenient and safe use of the public; it has not been uncommon, in later acts, to make provisions on these subjects; on the *Grand Western* it is enacted, that the ascents to the bridges shall not exceed $2\frac{1}{2}$ inches in a yard, and on the *Wilts and Berks* this rise is limited to 3 inches in the yard at the most. The width of the carriage-way, on the bridge, in the narrowest places, is also fixed in some acts, wherein we have seen 12 feet mentioned as a limit in some cases. We have before observed, that the canal ought, if practicable, to be conducted into deepish cutting, wherever a brick or stone bridge is to be erected, in order that the stuff may be thereby procured, for landing up each side of the bridge, and that the abutments of the bridge may be the more solid, and the foundations more likely to reach sound stuff, without an extra depth of walling, or the necessity of piling for such purpose. On this account it is, that the tail of a lock generally presents a proper place for a bridge, and where the walling, which must have been made for wing-walls, below the lower lock-gates, is avoided, or turned to account in the bridge. In places, where from the great traffic that is to be expected, or other cause, a towing-path will be wanted on both sides of the canal, the bridges should be made on a scale large enough to admit of a towing-path on both sides under the bridge, as in the two or three bridges nearest to *Paddington basin*, on the *Grand Junction*.

For *occupation*, or accommodation bridges, and even on some public roads, as on the *Sankey* canal, and others, a kind of swing or swivel bridge has in general been adopted, of which some mention has been made under our article *BRIDGE*. See *fig. 43 Canals, Plate VII.* A flat platform of wood strongly framed together, covered with planks, and having side rails, is prepared, wide enough for the purposes of a bridge, and about half as long again as the canal is wide, in the contracted walled part intended for the swing bridge. One end of the platform for this bridge is framed as light as can be consistent with strength, and the other very heavy, with provision for allowing large

stones or pigs of cast iron therein, so that the same will rest in equilibrio on a point at about one-fifth of its length from the heavy end; under this point, a large circular plate or ring of cast iron is fixed, having a smooth circular hollow sunk therein. An exactly similar plate is embedded, and firmly fixed on the solid wall at the side of the canal, except that this last has a strong iron centre or point standing up, to enter a hole sunk in the upper plate to receive it. On this pin the bridge is suspended in equilibrio, and in order that no impediment may arise to turning the bridge round, when its balance is by any circumstance destroyed, a number of smooth cast iron balls, of two and a half or three inches diameter, are placed in the circular groove or hollow ring in the two plates, which act effectually as rollers for lessening the friction between the circular plates, in turning the bridge on and off the canal; or, a ring containing several rollers (*figs. 45 and 47*), is substituted instead of the iron balls above-mentioned, between the lower and upper plates *figs. 44 and 46*. A recess is formed on the bank just to receive the bridge, when a boat is to pass, and when the bridge is turned across the canal, each end of the bridge (which ends are rounded into circular arcs, struck from the centre pin), slides on to a similar circular recess in the road, with a firm bearing at a very small distance below the ends of the bridge, when it is in equilibrio, on the centre pin and balls or rollers; by this arrangement it happens, that the heaviest loaded carriage, crossing the bridge, is not able to depress either end of the bridge on which it passes, in any sensible degree. The engineer should carefully avoid the use of these swing, or indeed of any moveable bridge, where the towing-path is to change from one side of the canal to the other, because the bridge must remain across the canal until a barge in passing, is got near enough for the towing-horse to cross over the bridge, and the bridge must then be turned off the canal before the boat can pass, and it continually happens, unless the towing-line is of great length, or is cast off at some distance before the boat arrives at the bridge, or the greatest dexterity is used, that the boat strikes the bridge before it can be turned off the canal into its recess: where several boats are closely following each other, these difficulties are much increased, and great delay must take place, or the bridge will soon be knocked to pieces. Swivel or turn bridges have sometimes been erected on the towing-path side, but they form there a most serious obstacle to the towing of boats; and on that account are generally placed on the off bank, and as no methods have hitherto been brought into general use, of turning on or shutting such bridges for persons to pass over them, except the persons, or some others, are at the time, on the same bank of the canal on which the bridge stands, in order to turn it over the canal; this has occasioned the necessity of clauses in every act, or set of bye-laws, requiring boat-men always to shut to every swing-bridge, or draw-bridge, as soon as their boat has passed. The great loss of time and labour in thus continually turning the bridges on and off, the wear that such continual use occasions, and the frequent damage which such bridges sustain from boats striking against them, if, by the least delay of the boat-men or accident, they are not turned off before the boat gets up; have occasioned our thinking a good deal on the subject, in hopes of devising some method of turning the bridge on when wanted, from either side of the canal; because such a contrivance would authorise the alteration of the present regulations, and require each swing-bridge to be left open, and out of the way of the navigation, except during the time that it was actually in use, by persons or carriages passing over it: another material evil would thereby also be remedied, that is, the difficulty which now exists of prevent-

ing the farmers' cattle, in the fields on the off side of the canal, from passing over the bridges, and escaping along the towing-path, without an expensive circle of fencing and a gate to separate the bridges from the fields, for no gate or obstacle can conveniently be made on the towing-path side to obstruct their passage. Chains and pulleys under the canal, and motion conveyed upon *Bramah's* patent principle, in pipes under the same, were considered among others, as the means of turning the bridge on, when wanted; but, our speculations hereon were, happily, at the moment of writing this (October 18 55,) interrupted by the information of a method, which was successfully brought into practice very lately, by Mr. *Benjamin Bevan*, the engineer upon the middle district of the *Grand Junction* canal, *viz.* near the steam-engine on the Wendover branch, where a swing-bridge of the common construction, with a railing or fence on each side of it, has an addition made to it, on the side that is next the canal when the bridge is open, or in its recess, at about three-fourths of its length, from the centre pin on which the whole turns; this consists of a jib like that of a crane, or the bars that are sometimes used for stopping carriages at the ends of streets: an upright piece of wood is hung by two hooks and thimbles, like those of a common gate, to the standard or upright on the side of the bridge; to the top of this a rail of 4 or 5 feet long is fixed horizontally, supported by a brace underneath, from near the bottom of the upright piece; on the top of the horizontal piece are two strong staples fixed, adapted to receive the thickest end of a very slender and light pole, such as are used for the handles of hay-rakes, but they must be longer, and rather larger for wide canals; a nail drove in between the staples through the pole fixes the same, and makes it form a light and easily renewable continuation of the top rail quite across the canal, so that a person, wanting to cross the bridge from the towing-path, can take hold of the end of the pole and pull by the same, and thereby turn the bridge over the canal; or, if a person has crossed the bridge towards the towing-path, he can with equal facility take hold of the end of the pole and shove the bridge round to the other side. The hinges of the jib that carry the pole are so adapted, that the pole has a tendency to hang directly across the canal, to the most convenient point for being taken hold of; but, at the same time it is with the least force turned round on its hinges until it is brought along-side of the bridge, and quite out of the way of boats that are passing. This very simple and cheap apparatus, we are told, answers effectually; no impediment is offered to the horse or towing-line; but when a boat arrives, whatever part thereof strikes against the pole, it recedes and suffers the boat to pass, and then by its own weight resumes its situation across the canal, ready for turning the bridge. The solid part of the jib is not made long enough to be liable to be struck by the boat, or a man standing thereon; and poles in plenty, of the proper size and length, can be in readiness, for replacing in a minute any pole which is worn out or broken by accident.

Bridges which have no towing path under them, present a great obstacle to towing, because the line must in those cases be cast off from the barge; except, occupation bridges, like the wooden one at Rotterdam in Holland, could be introduced, where the bridge, we are told, consists of two separate segments, each supported firmly on its own bank, and leaving a slit quite across the bridge for the towing-mast to pass through, and thus they avoid casting off of the line: this slit need not be so wide but that foot passengers can with ease and safety step across it; and, on the passage of horses or carriages, a moveable flap turning quite flat back upon hinges, might be turned over to complete the road.

Where swivel bridges of great width and strength are required, and need but seldom to be turned off, as for admitting ships at high water to the *West India* and *London Docks*, double wooden or cast iron swivel bridges are in use, with a moveable frame under each part, constituting parts of the ribs of the bridge, which frames turn on a hinge or joint, and are taken up or suspended by a screw at the other end, to clear the walls of the bridge when the same is to be turned off; and which, when the bridges are turned over to meet in the middle, can be let down by turning a winch, so as to fall in strong grooves prepared in the copings of the walls, and complete the abutments of the ribs of the bridge, as strongly almost as a fixed wooden or iron bridge could be made; an excellent example of which may be seen in Wapping street, crossing the entrance to the *London Docks*, as mentioned under the article BRIDGE. It appears that Mr. H. Shadwell was rewarded for some improvements to swivel-bridges which he suggested to the *Society of Arts*. See their *Transactions*, vol. xiii. page 227.

Draw-bridges are not uncommon as accommodation bridges on some canals: the frame or platform of them, with their side rails attached, is moveable on strong hinges upon the top of the wall or one side of the canal, and when down shuts into a groove prepared on the opposite wall, so as to present no projection or obstacle to the road over it. For raising these bridges, two strong and tall posts are fixed upright on the bank of the canal a little behind the hinges of the bridge; on the top of these posts are two very long and tapering pieces of timber called balance-beams, which turn on a hinge near their middle, their small ends being connected by chains to the further end of the bridge, to which the thick ends of the balance beams are made to be a counterpoise, by means of lead or iron nailed on to the same if necessary: when the bridge is shut, or prepared for passing over, the balance-beams rest nearly horizontal, there being a chain attached to the thick end of each, which hang down and can be reached by a man or boy, and by pulling at which, he can rear the bridge up upon its hinges for boats or vessels to pass. For crossing the Docks in Liverpool in different places, very large draw-bridges are in use, supposed to be the largest in England. But we are informed by Mr. Rennie, an engineer of the first eminence, that he has seen much larger draw-bridges in France. On the *Forth and Clyde* canal the draw-bridges are double, meeting in the middle of the canal when shut down. It appears that the Chinese have a sort of draw, or rather sliding bridges over the piers of the flood-gates of their canals, which, to prevent interruption to the masts of vessels, are constructed so as to be easily withdrawn when vessels are about to pass; they are flat wooden bridges, narrow and light, resting on rollers fixed in their frame, and running on a couple of loose spars that are withdrawn after the bridge. Wooden bridges are very often wanted for carrying the towing-path over the entrances to docks, or the side branches of a canal, and from their great span, to avoid a narrow place at the turning; these are often attended with considerable expence; they should be constructed of very sound and durable timber, well trussed, and as light as is consistent with strength, as they are seldom made wide enough to be used except by men and horses. We cannot too often advise that bridges of wood or iron, and stone ones also of large span, should be wider at the abutments, and diminish by a proper curvature of the sides to the middle, to prevent the strain of the materials on a sudden lateral impulse, from causing them to give way and cripple sideways.

The ingenuity and enterprise of British artists have given

rise within the last 30 years to an improvement of the first importance to river navigation, by the introduction of *cast iron bridges* of great span and height, by the adoption of which, in favourable situations, ships may be admitted further up into our large rivers; and in almost every case, the impediments to navigation may be removed that are occasioned by the narrowness and lowness of the arches of our old stone bridges, which not only exclude or interrupt the towing-path and necessitate barges to lower their masts, but in general cause such a fall in the water, owing to the deficiency of their water-way, as to be dangerous and impassable at particular states of the river. Near Coalbrook-dale on the *S Severn* river this improvement was first carried into effect, as particularly described in our article BRIDGE. A perfect model of this bridge, which is $100\frac{1}{2}$ feet span and 45 high within the arch, was prepared by Mr. *Abraham Darby*, who cast the same, and presented to the *Society of Arts*, in whose collection it may be seen by any one who applies in the Adelphi: see their *Transactions*, vol. vi. pages 228 and 232. Buildwas bridge of iron over the *Severn*, within two miles of the former, we have already described in the article referred to, and have only to add, that Mr. *Thomas Telford*, the engineer of this bridge, has given a plate of the same in *Phlymy's Agricultural Report of Shropshire*, page 316. For the principles on which the Wearmouth bridge, which we have described, is formed, Mr. *Rowland Burdon* on the 18th September 1795 took out a patent, which see in the *Repertory*, vol. v. page 361, where a view of this very curious structure will also be found. We are sorry to add that we heard lately in conversation, that this bridge has shewn symptoms of twisting or giving way side-ways, which have greatly alarmed some persons for its safety. The cast iron bridges at Bridgewater on the *Parret* river, and at Staines on the *Thames*, have been mentioned in our article referred to above; the latter, owing to the mistaken economy of the trustees, in having vaults made in the abutments, which ought to have been of solid masonry, gave way, and has been entirely taken down, as the new stone bridge erected before it, was obliged to be from the same cause. We cannot enough admire the prudent precautions of the select committee of the House of Commons in 1820, who investigated the different proposals for rebuilding of London bridge. (See *Tilloch's Philosophical Magazine*, vol. x. page 13.) They consulted the opinions of the most eminent professional men, and had a very accurate set of models, constructed in brass by Mr. *Berge*, the successor to the celebrated *Ramfden*, under the direction of Mr. *Atwood*, for illustrating the nature and properties of equilibrium arches. One of the designs which were presented to this committee, and which has since been engraved by Mr. *Wilson Fox* and published, is that of Messrs. *Telford and Douglass*, for a single arch of cast iron of 600 feet span, and rising 66 feet above high-water mark: as this scheme has not yet, nor ever may be carried into execution, it would be swelling the present article too much to detail the excellent provisions which the contrivers had made, for the execution and stability of this grand work. We proceed, therefore, to mention, that Mr. *Fulton*, in his treatise so often before quoted, has given designs (plates 14, 15, and 16), and explained the principles, page 120, of different bridges of cast iron. On the 24th May 1796, Mr. *James Fordan* took out a patent for constructing bridges which should be suspended from ribs of iron above: see *Repertory*, vol. vi. page 220, and on the 7th February 1797, Mr. *John Nash* obtained a patent for a method of constructing bridges of hollow quoins of iron, that can be filled with masonry or other solid matters after the bridge is put together; the piers of bridges he proposes in like manner to con-

struct of hollow cases of iron, to be filled with masonry after they are brought to their proper places: see *Repertory*, vol. vi. page 361. Of wooden bridges for large and navigable rivers, we have given an example in the once justly famous Schaffhausen bridge over the *Rhine*, in our article *BRIDGE*. Mr. *Fulton* mentions a very famous one at *Wettingen* in Switzerland; and has given us designs for bridges for newly settled and woody countries, wherein large timbers dowelled together, supply the place of key-stone, above which the platform for the road is to be supported. The same gentleman has proposed in constructing the above kind, or iron bridges that are very flat and low, to obtain the necessary stability of the buttments, by continuing the line of key-timbers or ribs with their proper curvature for some distance into the bank on each side. We have before spoken, under the article *BRIDGE*, of the proper form of the projecting angles of the piers of a bridge, and shown that for navigable rivers, sharp corners should be avoided, from the damage that such might do to the boats and vessels.

Bridges will be wanted in the construction of rail-ways for carrying the rail-road over rivers, sudden valleys or roads; some of these may require cast-iron arches; some of them must be of stone or brick; but oftener, such may with propriety be constructed of wood, taking care that they are effectually trussed, or formed on the best principles, also that the joints are effectually secured from wet, and the whole covered with a coating of mineral tar or paint, to be renewed from time to time to keep out the weather. One other thing remains to be mentioned respecting bridges, i. e. owing to the contraction of the canal and curvature of the towing-path at a bridge, the towing lines are apt to fret and wear away the corners of the bridges, occasioning also a great waste in ropes: for remedying this, light hollow cylinders of wood are placed upright, or nearly so, according as the wall is upright or battering, at all the corners of the bridges or other obstructions to the direct line of the towing-path; these cylinders being hung on centres or pivots, at top and bottom, they turn round by the action of the rope, and prevent friction and wear.

The *Towing-Path*, horse-path, or hauling-way of a canal, should always be on the lower side if practicable, the traffic on the same having a tendency to consolidate the new made bank, to prevent the accumulation of weeds and the harbour of vermine, that by lodging in and perforating the bank might endanger the same. The towing-path should change as little as possible from one side of the canal to the other, and when this is unavoidable, it should be always done at some fixed bridge, to avoid the inconveniences before pointed out; the change ought never to be made in deep-cutting, as has been done near *Tring* on the *Grand Junction*. The towing-path ought never to be interrupted if the same can be avoided; and, besides having a way under all bridges (except those where a change of sides is to be made) we hope to see the example followed, which has been set at *Atcham* on the *Shrewsbury*, and *Newbold* on the *Oxford* canals, of continuing the towing-path through the tunnels, wherever the same shall appear practicable. On the proposed *Bude and Launceston* canal, it was intended to form a towing-path on both sides; a hint that may prove very useful in some situations of greater traffic, than there ever was likely to be on this canal. It is often provided in the act, that the towing-path may be used by the owners and occupiers of land on the line as a bridle-way, or as a drift-way for their cattle; as on the *Ashby de la Zouch*, *Grantham*, *Leicestershire and Northamptonshire Union*, *Oakham*, &c. Frequently, permission is given to persons to use the towing-path as a foot-path or bridle-road, and we think it would in some

instances be proper to obtain the power of levying a small toll on horse passengers; if the company should at any future time see it right by public notice to permit their towing-path to be so used. It seems inapplicable to the purpose of a towing-path, to make public drift-ways of them in any case, on account of the damage which loose cattle would do to the banks and fences, and the impediments which droves of cattle would present to the hauling-horses and lines. In forming the towing-path, care must be taken to make the ground found, and to cover it with a proper thickness of good gravel; and we cannot but recommend the raking or sorting of this as it is laid on, throwing the large or irregular stones forward to be covered with better gravel, so that the surface may be smooth and even, without rough and large stones to throw the horses down, and render the use of the path unpleasant. On the duke of *Bridgewater's* canal, where proper materials for road-making are very scarce, the shale and slates, or refuse coals from the mines are brought out and calcined, or burnt in very large heaps, the cinders of which are used for making and repairing the towing-paths upon his canal. The height of the towing-path ought not to be less than one foot, or more than two or three feet above the surface of the water, or top-water line.

The *fencing* of the sides of a canal is a business deserving of more attention than has been usually paid to the same. Quick-set or other live fences ought by all means to be made, except in the case of a rocky country, where good and durable walls can be built at an easy expence: rail or pale fences are very improper, except in and near towns, on account of their heavy expence in repairs. The continual weeding which quick-fences require, the great injury which the plants sustain from weeds, if the same are at any time suffered to grow up, and the damage which the pulling or hoeing up of weeds so repeatedly, do, in wearing away the soil, and more or less exposing the roots of the quicks, and besides these, the plants being often wounded in their tender bark by the hoes used by the weeders, are most serious difficulties in the raising of quick-fences, wherever our experience has extended, except in the north-eastern parts of Norfolk, where the spirited and intelligent tenants, that there abound, have a method of raising fences, which they are continually doing during the currency of their leases, that we are happy, in this instance, of being able to mention, because it has not yet, we believe, appeared in print. The line of an intended hedge and ditch being marked out, the first step is to collect carefully all the top-soil or vegetable mould into a ridge where the centre of the bank is to be, and if this vegetable mould proves too abundant, the extra quantity is thrown into heaps further off, in order to be mixed with dung, or carted to some parts of the land, which wants a greater staple of mould. Thus done, a row of spits or lumps of earth out of the ditch are laid carefully in the front of the bank, and on these, when reduced to a regular line by paring with the spade, the white-thorn sets are placed a little inclining upwards, at about four or six inches apart; care is taken in laying in the sets, that their roots are bedded in the vegetable mould, that is to form the centre of the bank; when this is done, another row of spits or lumps is dug out of the bottom of the ditch, and laid upon the quicks, which being patted down and levelled at top with the spade as before; another row of quick-sets is laid in, taking care that each plant in the upper row is over a space in the lower one, and that their roots are inclosed in the top-soil. Other fods are then dug out of the ditch and piled up, with the proper slope or batter, until the bank is raised to the intended height; the vegetable mould is then dressed up into a regular bank at the back, and the remainder of the

stuff from the ditch is thrown over, and is afterwards carefully spread and laid up against the back of the bank, so as entirely to enclose the vegetable soil in a case of dead earth, or stuff taken from below, where cultivation has deposited the seeds, or nature the viviparous roots of such plants. Still further to accomplish this exclusion of the soil in the bank, from the action of the sun, air, and other stimulants to vegetation, at a proper season in the spring, a quantity of dead earth is pared up from the bottom of the ditch, and worked and chopped about, until it is in the state of *puddle*, before described. The tops of the quicks are cut off nearly even with the ground, after which, a labourer carefully plasters every part of the face of the bank with this prepared or puddle-like stuff; and after it is laid on, having a pail-full of water at hand, to wet his spade in if necessary, he works this plaster about, giving the flat surface of his spade exactly the circular and plastering motions that plasterers use when at work on a ceiling or wall. If it should appear that frosts have mouldered down, or injured the facing of the bank, the same is carefully repaired and worked again, as above, before the season for the vegetation of the quicks. As soon as the white-thorns have put forth their leaves in the spring, a careful labourer walks along the ditch, with a knife in his hand, and wherever a plant is milling, from among those which have shot forth, he digs in the point of his knife with care, to find and release the top of the set, which otherwise might be smothered and confined by the plastering of the bank. The benefit of this procedure is inconceivably great, in almost totally preventing the growth of weeds, and in confining the moisture in the vegetable mould from escaping in dry seasons. At a time in the summer, when every part of the surface was covered with vegetation, we have with pleasure examined some miles in length of quicks treated in this manner, and although the quicks had made the finest shoots which could be imagined, not a vestige of vegetation of any kind besides was to be found on the bank; and thus, with proper care in renewing the plastering or working of the bank, many of them remain until the quick is grown up to be a fence; and it is almost literally true, that weeding is here unnecessary, although no soil can be more congenial to, or worse stored with the seeds of annual weeds, than some of those were of which we have been speaking. The ditches are made deep, and the sides of them as steep as the soil will stand in the general, so that dead or guard fences are generally omitted on that side; and so they are often on the other, or back side, and a prick-hedge is substituted, which, with care, and the letting of sheep only loose in such fields, answers the purpose very well. Some time before the bank is made up to the intended height, the labourer goes along upon the top of it, shovels off the loose top, and treads down the top of the bank so as to form a flat of perhaps 12 or 14 inches wide; into the centre of this he strikes in his spade, and gives the same a lunging motion, so as to open a narrow and deep notch; this operation he repeats, until a notch of this sort is opened the whole length of the bank; he then proceeds to stick this with short and rough bushes, so close as to make a complete hedge; he then throws up out of the ditch as much stuff against the bushes as will lay on the plane or top, in which the hedge is struck, and beats the same down strongly with his spade; the same process is followed at the back of the hedge, by which these bushes are so securely set into the bank, that they will often stand until the quick is become a fence; in places where the destructive pilfering of the poor is properly repressed. Some may perhaps consider us as going here too far into the subject of fencing, but we request of such to consider how important the subject is to a canal-

company, which may have to raise much more than a hundred miles in length of quick-fences, as was the case a few years ago with the *Grand Junction* canal company, and some others, some of whom are still feeling the very heavy burden of weeding their quicks two, three, or four times annually; which an adoption of the above principles would, we are certain, have tended to reduce most materially. See our articles *ENCLOSING, FENCING, &c.*

The quick for a canal ought to be placed a little above the level of the towing path, and be separated therefrom by a small ditch, to prevent the towing-horses from biting or trampling on the quick; but the principal ditch, where the sudden falling away of the off-bank does not answer the same purpose, ought invariably to be on the field side, for keeping the farmers' cattle at a proper distance from the quick, and to check their attempts at jumping through or over it. The quick ought not to be placed too near the towing-path, and the hedges should be carefully cut and plashed about every twelfth year, both to preserve them vigorous and in good growth, and also to preserve the towing-path clear. On the *Oxford* canal, near Braunston, we remember that the hedges were so grown over the towing-path, in the year 1799, that it was quite dangerous riding along, and the horses were driven so near the edge of the canal, by the intrusion of the bushes on the path, that the bank was suffering materially. In places where the canal is embanked, it will be proper to place the hedge at the bottom of the slope, in order to enable the company the better to prevent the growth of rank and large weeds, and the consequent harbouring of vermin, which would lodge in the bank: steep embankments might also be materially damaged by the treading of cattle on their sides. Through common fields, or very large pastures, it is sometimes not necessary to fence off the towing-path therefrom, but at the boundaries or entry to such fields, a gate is placed in the towing-path, to prevent the intermixture or escape of the cattle; and generally these gates are double, falling rather forcibly towards each other, by which construction the cattle are prevented from pushing, or the wind from blowing open the gates, as would otherwise often happen.

At the termination of every principal estate or farm that adjoins the towing-path, it is usual to place a swing gate across the same, to prevent cattle getting away, in case they should break, or by accident get into the towing-path. Cylinders should be placed, as before described, against each of these gates for the towing-line to run upon; and side rails should be placed inclining up to the top of the posts, to assist the rope in getting over the same.

Draining is another expensive business, of which a canal company will have a good deal to perform, in most cases. Soon after a canal is filled with water, and often sooner on the upper side, owing to the course of the land-springs, and those of a more permanent character being intercepted by the puddle-ditches, wet places will appear on the land, which would, if neglected, become unfit for cultivation; these are often of considerable extent below the canal; and the committee of the canal company must not be surprized at hearing the farmers attribute many wet places in such situations, to the soakage of their canal, that really are not affected thereby. It would be of use, and the source of much satisfaction, if the resident engineer were to note down in his book all the wet and springy places that appeared on the sloping land, below the level of the canal for a considerable distance, and the condition or run of water from each before the canal was made; because the appearance of new quagmires, as the farmers in many parts call them, or the increase or enlargement of others, is often the first and only indication of

an increasing and hurtful leak from the canal. The committee should not be nice in drawing the line, as to the extent of draining which they order to be done; but it would, on the contrary, be highly to the credit of their concern, and the interest of future canal schemes, to bear the whole or a portion of the expence of effectually draining all the land, whose wetness could, even in mistaken prejudice, be ascribed to their canal. The execution of these operations ought not to be confined to the quackery of boring a hole here and there in a trench, without any theory or meaning; but the resident engineer, or some professional man employed expressly for the purpose, should, by a judicious application of his experience and knowledge of the *strata* in every place, apply that particular method of draining, as to the situation and depth of the drains, &c. which every spot may require. And these operations are more various and important than what any person, who has not made the subject his particular study, can possibly be aware of. See our article DRAINING. There is a danger attending drains made near a canal, from rats or moles working their way unobserved beneath the surface, between the drain and the canal; for detecting which, or other leaks, it will be proper for the resident engineer to enter in his book a minute description of the situation of the mouth or vent of every drain, choosing situations for the same, when they are made, in ditches, where they can be readily got at, and not be liable to be damaged by time, or the treading of cattle. The length and direction of every branch of under-drain which vents at that mouth, should be noted down, and the quantity of water which the drain discharges should also be carefully estimated, at some short distance of time after the same is finished; and a regular and periodical inspection of these drain-mouths by the engineer with his book in his hand should be made, by which any secret leak could hardly fail of being detected. It is almost unnecessary to point out the importance of an attention to these circumstances, in situations where water is very scarce.

The construction of Boats for canals and rivers requires some notice in this place. Mr. Chapman, who has given some excellent directions respecting the form of boats least liable to overset or be injured by heeling, has very properly observed (*Observations*, p. 102.), that the area of a cross section, of a boat to be used on a canal, ought not to approach so near to the area of a cross section of the water in the canal as 1 to 3, or considerable inconvenience will arise, both from the increased resistance of the boat, and the damage to the banks, from the counter current to fill up the space the boat leaves in her rear. This circumstance requires particular attention, particularly in boats that are to move quick, like the passage-boats from Manchester and Paddington, on *Bridgewater's* and the *Grand Junction* canals: in the former of these, we observed a constant elevation of the water before the passage boat, as it moved along, of at least 9 inches, and perhaps more than a foot at times; and the rapidity with which the water ran backwards, between the boat and the sides of the canal, appeared to have a most destructive effect upon the latter, particularly on the towing-path side; and often this was laid quite under water, for considerable distances together, by the surge or wave opposite to the head of the boat as it passed along: while the labour of towing was most materially increased. We regret that we had not the means of ascertaining, how much the head of the boat was elevated upon this artificial wave in the general, and up which inclination the towing mules were constantly drawing it. Some attention ought to be paid to the form of the head and forepart of the boat, with a view to its letting the water pass freely off by its side: flat headed

boats, and those whose ends are rectangular in particular, ought not to be towed fast, or great loss of labour and damage to the banks will be the consequence, unless the canal is very wide and deep. It has been proposed to form boats sharp at one end and flat at the other, so that the flat ends being joined, two of them may form a body, diminishing properly at each end, for easy passage through the water, and for steerage. Mr. *Nicholas King*, an American, has proposed boats in four parts, that can be detached when the same are to pass an inclined plane, and be afterwards rejoined. Since the use of cast-iron has become so general, Mr. *John Wilkinson* has constructed boats and barges of iron, some of which are used on the *Severn* river, and others upon the different canals in Staffordshire, Worcestershire, &c. Mr. *Robert Fulton*, in his *Treatise*, p. 31, has proposed and described a kind of rectangular boxes, with low wheels (or rather trucks, as the axle and them are to be cast in one piece) fixed under their bottoms, to be used upon canals instead of boats, on account of the use which he proposes to make of them, upon inclined planes and rail-ways, as well as on the water, as we have before mentioned. Mr. *William Chapman*, who has examined this system particularly, in his *Observations*, has proposed and given drawings of wheeled-boats of a different construction, larger wheels let into the bottom of the boat being used; and his boats are so contrived, that several of them, linked together by their ends, can be used together either upon a canal, or a rail-way, or plane. The same author has recommended and described a kind of flat-bottomed boat, with a single or double rail-way on its floor, which he proposes to receive or discharge a loading of rail-way waggons, as it lies in a shallow dock, from which the water has been drawn, and to which it is to be again admitted when the boat is to float out into the canal. For ease in getting loaded waggons in and out of these boats, a pair of leaves, or water-tight flaps, are contrived to let down, and permit the junction of the fixed rail-way on the land and the part thereof that is on the floor of the boat. A curious method of steering boats is in use on the *Bedford, Ouse*, the *Cum*, and others of our eastern rivers: two boats are always used together, one of them having a strong pole, or bowsprit, projecting horizontally from above its prow; this is brought over the stern of the boat which is to go before it, and the prow or stem of one boat is fastened by a rope close to the stern-post of the other: to the first boat the towing-line is fixed, and the bowsprit of the last boat is used as a tiller to set or retain the last boat to any required angle with the first, by which the last boat acts very effectually as a rudder for steering the first. Mr. *Chapman* proposes to adopt this principle with small boats upon canals. The west-country bargemen, on the *Thames*, guide or stop their boats, as they are floating down the stream by a long and strong pole, with iron prongs at bottom and a cross handle at top, round which they dexterously wrap a short rope, fastened to the side of the barge, when the pole has struck into the bottom of the river.

For speedily emptying the cargoes of small boats into larger vessels, Mr. *Davis Dukart* contrived, on the navigation to the *Dungannon Collieries*, to float his small boats on to cradles or wheeled carriages, on which they were dragged up a short inclined plane, and upon a rail-way conducted over the barges in the basin; and then the boats could be turned over, and their contents shot at once into the barge. A different method, as Mr. *Chapman* informs us, is practised in South Wales: it consists in continuing the canal (which may be a wooden trough) to the place of discharge, and terminating it on a caisson, suspended on a transverse centre; the boat being arrived at its place, the end of the canal is

closed by a stop-gate, and the small quantity of water contained in the caisson (which the boat should as nearly as may be fill) being let out, the caisson with the boat in it may be turned over, as already described.

The *moving of Boats* upon canals or narrow rivers, where sailing is impracticable, has always appeared attended with considerable difficulties. Where the width and depth of water will admit, long oars have been used, worked by one or two men on each side of the vessel, as is done on the coal-barges and lighters on the *Thames* in or near London. On the *Tyne* river at Newcastle, their keels are said to have been in use ever since 1378, and are rowed by an immense oar on one side, another being used at the stern to steer by, and counteract the tendency of this strange mode of rowing. It is said that the large oar is hung by an iron ring, so as to admit of its being laid on the gunwale of the keel, when not in use, but not of its being removed. Owing to the want of any regular and proper path on which horses could travel by the sides of rivers, the first hauling or towing of boats was performed by men, as still continues to be the case on the canals of China; and in this country most of our navigable rivers were without horse towing-paths till of late years. Within our recollection, ten or fifteen men were seen tugging at the hauling line of a barge on the *Thames*, in the meadows of Twickenham. A good horse-path now begins at Putney bridge, on the south side, and continues uninterruptedly on one side or other of the river to the extreme points of the navigation. These essential appendages to navigation are but now completing on the *Severn* river, which has been so long famous for its navigation. The towing-path on many of our old navigations is continually interrupted and broken off, by mills and other obstacles, without any bridges for the crossing of the towing-horses and boys. On the *Ouse* river, below Bedford, we have observed the towing-path to be interrupted at the end of almost every field, by high and dangerous stiles, over which the ill-fated navigation-horses have to leap, encumbered by their harness and the heavy rope. No regular path is maintained, in a great part of the distance, by the owner of the navigation; but frequently the fine meadows there are cut up, by the track of the horses being at a considerable distance from the river, across the many bends that it has; and the farmer's graze, between this path and the river, is rendered of little value, by the soiling and dragging of the hauling-rope over it; the banks of the river are also miserably worn away, by hauling so far from, and consequently so obliquely to, the direction of the stream. In many places, where the river is wide, there is no track for hauling, except along the bed of the river itself; where often the horses, with a wretched boy upon one of them, are seen sometimes wading, and at others swimming, along the course of the river! Nothing is more common than seeing the horses and boy have to swim over from one side of the river to the other, when the hauling-way changes; not unfrequently this is impracticable, from the total want of a way on either side, and the poor horses are obliged to leap from the bank, perhaps when at a considerable height and distance, into the head-room of the barge, to the great peril of their bones and neck: shortly after, these wretched animals, and probably with a boy on their backs, are forced to jump out again, and perhaps plunge into the deep river and swim on shore, to resume their labour of towing. A correspondent of *Dr. Anderson* has expatiated (*Recreations*, v. 318.) on the barbarous sight of six horses harnessed at length, towing a barge up the *Thames* above Putney, by a single line of insufficient length, by which the hind horses were in continual danger, in spite of their utmost exertions, of being precipitated into the river: what would this humane gentleman have

said, if his walk had been along the banks of the *Ouse*, on a piercing winter's day? It is owing, in a great measure, to the enormous difficulties and expence of constructing and maintaining a proper horse-path by their side, that the navigation of many of our rivers is so imperfect. In all flat countries, except the river is embanked, as in Cambridgeshire, Lincolnshire, &c. and without any wide wath or fore-ground within the banks, the towing-path often cannot be made up above the reach of the floods, but, during every flood season, will be under water and useless; and perhaps, when the water subsides, it will be found carried away by the force of the current for great lengths together. On some of our canals, the practice at first prevailed of towing by men; and the same still continues on the *Stroudwater* canal, whose towing-path has stiles upon it, like those of a foot-path, at the divisions of different persons' lands. Horses are now, in general, used for towing boats on our canals, except the late duke of *Bridgewater's*, who reared a large and fine herd of mules, that were found to answer so well, that none others are used to this day, we believe, on that canal. Except with passage-boats, and flies or packet-boats, for the expeditious conveyance of packages and parcels, the usual rate of tracking or towing upon our canals is about $2\frac{1}{2}$ miles per hour, including the time lost in passing the locks, which, if of 8 feet rise, will require about $5\frac{1}{2}$ minutes each.

It is certain that there is hardly any limit to the load, which one horse can move, in a number of barges attached together, when going with a proportionally slow pace; and this has occasioned some canal advocates to assert that one horse will, on a canal, draw as much as 60 on the road; while Mr. *Robert Marshall* has asserted, that horses will not be able to move more than 15 miles per day with deep laden barges on a level canal. On most of the wide canals it is usual to employ a horse to each barge, or to a pair of boats of half the width each that the barges are. It appears, that on the *Ketley* canal, on *Bridgewater's* canal between Worsley and Manchester, and others, several of the small boats in use thereon are linked together, and drawn by one horse or mule; there being projecting and smooth rails provided on the *Ketley*, at all the convex points of the bank, to keep the boats in their proper track. Mr. *Fulton* has imagined, that 15 or 20 of his small rectangular boats, linked together, could be drawn by one horse, and be kept in their proper line upon the canal by a man with a boot-hook walking by the side of them on the towing-path. Besides the methods of rowing and tracking, which we have been mentioning, on the *Tyne*, the *Thames*, and most of our rivers, hitches, sets, ploys or poles, are used for shoving of barges along: the gunwale of the keels or barges is made wide and convenient to walk upon, and the boatman, being at the head of the barge, sets his hitcher against the bottom and shoves against it, walking along the gunwale of the barge until he has arrived at the stern; when he draws up his hitcher quickly, and returns to the head to repeat the same operation, and this sometimes on one side of the barge and sometimes on the other, unless there are two men so employed, whose equal action could keep the barge in its direct course. This last method might be more used than it is upon canals; but from the necessity which most of them have found, for prohibitory clauses in their act, against the use of any pointed poles, particularly such as are shod or tipped with iron, on account of the damage which such often do, by penetrating and disturbing the lining and banks of the canal, and causing it to leak. We have heard of an attempt lately, to introduce a kind of hitcher-iron on the *Grand Junction* Canal, which should present a flat end or surface, sufficient to prevent its penetrating the facing on the bottom or sides of the canal, and having a small turn up at

the point, which might remedy the loud complaints of the boatmen, at being debarr'd a hooked pole on board their boat, by which a comrade, who has the misfortune to fall overboard or into a lock, might be dragged up to the surface of the water. We have thought that it might be worth while, particularly in crooked and difficult parts of a canal for hauling, and where rubble stone or gravel is in plenty, when a wide canal is cutting, to form the covering of the lining, or the facing of the bottom, and perhaps of the lower part of the sides also, of gravel or rubble instead of earth, and carefully to level and ram or roll the same down like a road, so that hitches might be used freely thereon as on the bottom of a river. There would still, however, require very strict and well enforced regulations, to prevent the walls of the bridges, locks, tunnels, &c. from being pecked and greatly damaged by the points of the hitches. Slide-rails will also be necessary, in and near the locks or tunnels, as we have mentioned in speaking of the Blisworth tunnel, which can, without damage to the walls, be removed, when decayed or worn out. Before we proceed to the subject, that has perhaps produced the greatest number of unpractised mechanical inventions that are any where else to be found, we mean for *moving boats* by an impulse from within or accompanying them, we have one other thing to mention, viz. that Mr. *James Jordan*, in his patent of the 24th of May 1796, for bridges, before quoted, has proposed the use of circulating chains across an aqueduct bridge, for towing boats over the same; and avoiding the expence of the extra width for, or lateral support of, a towing-path thereon.

The volumes of the *machines approved by the Academy at Paris*, and the *cabinet of M. de Servier*, printed in 1719, contain plates and descriptions of many different contrivances, designed for *propelling or rowing of boats on canals and rivers*; one kind of these, which we shall first notice, depends upon gaining an impulse or hold against the ground at the bottom of the river or canal; in one of which, a small boat moved by oars was proposed to be employed in successively carrying forwards and dropping anchors whose ropes were to be attached to a horse-gin on board of a barge, which was designed to tow or drag a great number of others. In another, a spiked wheel was proposed to roll on the bottom of the canal, attached by a frame moveable on hinges at the stern of a barge, where a roller turned by a winch, was to give motion to the spiked wheel and propel the barge, by means of an end's rope or chain. See also *Walker's Lectures*, 4to. page 350. A second kind depended upon the same principles as an oar, except in the construction and mode of applying the power. On the 20th of July 1796, Mr. *Thomas Potts* took out a patent, for the use of a large flap or oar, moving on an horizontal hinge, upon a framed lever at the stern of a barge, intended when the handle of this lever was lifted up by several men, to turn on its hinge and present but little resistance; but on the descent of the lever, its whole surface was by the action of the men at the lever, to be exerted on the water for propelling the barge: see *Repertory*, vol. vi. p. 160. In the year 1801, Mr. *Edward Steers* took out a patent, of which we have seen only a short extract in the *Monthly Magazine*, vol. ix. p. 486, from which we understand his invention to differ but little from the above, except in having two paddles or oars. Mr. *Robert Baisson* took out a patent, for applying the principle of luffer-boards or venetian-blinds to several purposes, which he has explained at length in his *Essay* printed in 1798; and at page 60, proposes to propel ships by large oars or fins of this kind to be hung on the sides thereof by hinges, and worked by a lever, as a rudder is by its tiller; poles with square frames fixed on their ends, to push against the water

behind the vessel are also described. A third kind, depending on the reverse of the action of an underfoot water-wheel, has had many advocates; the first that we have met with in our own country, is Mr. *Thomas Savery* in 1698, whose contrivances are shewn in *Harris's Lexicon Technicum*, art. Engine; it consisted of 6 or 8 paddles like those of a water-wheel on each side of the vessel, fixed on an axis across the same, on which was a trundle head, and under this a wheel working into the same, by the force of a capstan to be turned by men. We are told, that in the year 1781, the *abbé Arnal* proposed to apply the power of a steam-engine on board of a vessel, for working paddles, something like the above, we believe. Soon after this period, we remember seeing on the shore of the *Thames* at Westminster, a small barge with a water-wheel in a cavity in its stern with a steam-engine for working it, which was said to be the contrivance of *earl Stanhope*, and had been tried with success against the tide in the river. In the year 1797, a vessel having rowers by its side, that made 18 strokes per minute, from the action of a steam engine on board, was tried on the *Sankey* canal near Liverpool, by which it was propelled 10 miles and back again to the same place: see *Monthly Magazine*, vol. iv. p. 75. In the same year, Mr. *Walker* (the lecturer) made some experiments on the *Thames* at Reading, and caused a boat to row itself against the stream. See his *Lectures*, 4to. page 349. About the year 1800, *Messrs. Hunter and Dickinson* took out a patent, for a propeller for ships, which was tried in January 1801, on board of a government sloop off Deptford on the *Thames*, and the sloop thereby made way against the tide at the rate of three knots an hour. *Monthly Magazine* vol. xi. p. 195. In the *Journals of the Royal Institution*, about the year 1803, there is a description of an improved application of the steam-engine, to the turning of a wheel for propelling boats; the cylinder of this engine is horizontal, and the wheel with paddles is in a cavity in the stern of the boat, which therefore has two rudders, one on each side of the wheel, connected together by cross rods. A vessel of this kind was constructed for the *Forth and Clyde* canal company, under the direction of Mr. *Symington* the inventor, and in a trial made in December 1801, it drew three vessels of 60 or 70 tons burthen each, at the rate of $2\frac{1}{2}$ miles per hour on their canal: see *Agricultural Magazine*, vol. vii. p. 152. We read in the last mentioned work, vol. ix. p. 218, that Mr. *Robert Fulton* exhibited a vessel on the *Seine* at Paris, in August 1803, having two wheels with paddles, worked by a steam-engine, and that two other vessels were towed by it against the stream at the rate of 3 miles per hour. A fourth kind of boat propellers, has depended on the rotary motion of a screw, or fliers like those of a smock-jack; Mr. *Daniel Buftnell*, in his attempts to navigate sub-marine vessels, as related in the *Transactions of the American Philosophical Society*, vol. iv. p. 303, used oars, placed near the sides and top of the vessel, formed upon the principle of a screw, the axles of which entered the vessel, and by turning the same one way, the vessel was made to advance or descend, as it was to recede or ascend by a contrary motion of the screw. Mr. *John Vidler* has contrived a vessel, which has been lying, and occasionally tried in the *Thames* at Westminster, for 2 or 3 years past, that has a boom hung by an universal joint (Hook's) at the stern thereof, to a rotative axis, turned by a capstan upon the deck of the vessel; at the end of this boom is fixed a circle of strong flyers, just like those of a smock-jack, which by striking the water obliquely as the boom is turned round, propel the vessel forwards; near to the flyers there is a collar on the boom that turns easily therein; to this collar ropes are

attached, which go to different parts of the stern of the vessel, and by which the boom, when in motion, can be drawn up quite out of the water, if its propelling action is wanted to cease on any temporary occasion, or the flies thereof can be let down into the water to any depth which may be required, or be turned aside from the direct line of the vessel to steer her on any course, without wasting so much of the propelling power upon the rudder as is usually done in steering; a rudder is however applied to the vessel ready for use when occasion may require. The fifth and last method, which we recollect to have seen or read of, consists in pumping water, by a force-pump through an orifice or pipe at the stern, or end of the keel of the vessel, with such force as to propel the vessel along, by the stroke of the moving column of water against the water, in which the vessel floats; we are sorry that our memory does not serve us to mention the name of the inventor of this method, or the work wherein we saw a description of the apparatus. In the *British Magazine*, vol. i. p. 397, it is mentioned, that in the year 1800, a vessel was constructed at Liverpool with a steam-engine in it, which was moved along without the intervention of any machinery; we think this as likely to have been, an application of the pumping principle above mentioned. Although, as we hinted above, none of the mechanic contrivances here mentioned have been adopted in practice, we trust our readers will not be displeased, at the short notice which we have given of each, with a view to preserve their memory, and in hopes that the thing may yet be accomplished.

On the *repairing of Canals* we think it necessary to say something; and to begin, by recommending the adoption of a system of management, by which the earliest notice of any defect, or want of reparation, will be obtained: that in store-houses, at proper places on the line, a stock of oak, elm, and deal timber should constantly be kept, cut out and seasoned, ready for replacing any of the timbers or planks in the locks or other works, with the least possible delay to the trade; a circumstance which, if not attended to, may prove of incalculable injury to the credit and success of the concern. Sound and good bricks, and stones, ready for replacing any which are liable, or observed to be likely to want repair, should also be in readiness, and good cement should always be kept in readiness, on some part of the line from whence the quantity wanted may be speedily transported to any part where a reparation of the walls, bridges, culverts, &c. may require the same: however, before emptying any part of the canal, or interrupting the trade for any reparation, a strict search should be made throughout every part in that level, or on the adjoining ones, to discover all the defects therein, that arrangements may be made beforehand for repairing the whole at once, or with as little delay as possible, while the trade is interrupted on the line. In every store-house a considerable number of the *pile-planks* before described should be kept piled up in readiness, for making temporary flanks or dams, in order to empty any particular part of a level, which may have a culvert, trunk, sluice, stop-gate, lock-sill, or other thing which is damaged, out of order, or decayed. It is surprising, to those who have not seen such works performed before, with what facility the workmen who are used to this business will drive two rows of pile-planks so regular and close to each other, that by the help of the tongues or slips in their grooves, and often without, a tight flank is made without any earth or other loose matters to stop the water; and between two of these flanks, if such are necessary, they will empty the water, by chain pumps, or water-screws, to get at any culvert, or other matter, to be repaired or altered; there have been instances of these operations being performed, and of the part being filled with water, and the plank-piles

drawn up again for the trade to pass, in the space of eight or nine hours. Should any part of the canal appear to want new lining or puddling, owing to a neglect at the time of making of the canal, or to any subsequent accident, care should be taken to choose the time for such works, when the trade can best bear an interruption; and as, on the average of seasons, the trade is two or three weeks interrupted by ice, during the months of January and February, it may not be amiss to embrace that period, on some occasions, although the work may be longer about, and some additional expence may be incurred by covering up the work with earth, before it is left at night, to prevent its freezing, and in removing all such puddle, &c. again in the morning, or at beginning work, which shall be found frozen. Previous and explicit notices should be given of all intended interruptions to the trade, as long beforehand as is necessary, to enable the traders to supply stocks of articles at the places of consumption on the line, and to avoid having their barges locked in, and perhaps lying idle, when they might have been employed if they had been on a different part of the canal.

It is an essential point of good management to have experienced mole and rat-catchers employed from time to time upon the line of a canal, to extirpate these hurtful vermin; and in every instance of discovering one, to trace out all his burrows and holes, and have them carefully stopped up and filled in every part, as well for preventing the harbouring of other animals of the same sort, as for preventing the water from making its way into and through them. On a canal in Surry, we are told by Mr. Robert Marshall, in his *examination of a canal and rail-way*, &c. that a mole or rat hole only, occasioned, after the hard frost of 1795, the rupture of the canal in a high embankment, by which more than 100 yards in length of a lofty bank was precipitated into the meadows and river below, and that a barge which before lay enveloped in the ice on the canal, was hurried down through this gulph into the river! It is impossible to take too much care against such fatal disasters as these, and the duty of the mole and rat-catchers ought not to be limited to the company's ground, but in all fields, banks, ponds, or brooks within 100 yards or more of the canal, on each side, they ought to be equally attentive to the destruction of such vermin, and the demolishing of their secret retreats. The same men might very properly be employed in pulling up and extirpating all large and spreading weeds from every part of the banks of the canal, and in mowing down the herbage occasionally; these circumstances being not less essential for the neatness and beauty of the canal, than to prevent the first harbour of vermin of different kinds. The banks of the canal will be very apt to continual wear at the surface of the water, and for some height above and below that level, if a proper kind of herbage is not encouraged upon the slope of the bank: considerable care should be taken to suffer no plants to take root on or near a canal bank, or spread its seed, (if possible to prevent it where water is taken into the canal by a feeder), which will grow in deep water, or whose roots are large, hollow, and strike deep into the ground, lest the former of these should choke the canal in time by weed-beds, and the latter render it leaky by the formation of numerous open tubes through the lining into porous stuff. None but those who have seen many drains or new ditches opened in wet and boggy ground, can be aware of the depth, size, and number of hollow roots, which some of the aquatic plants, as the *equisetum palustre*, or marsh horse-tail, the *iris pseudacorus*, or yellow flag, and several others, send forth into the ground.

Puddle-ditches, in the banks that are raised or made up, are a great security against the bank being washed down,

in case of the water, risen by any sudden thunder-shower, or other inordinate rain, breaking over the top of it; as soon as the puddle is reached, the effect of the stream to tear and lower the bank will often be stopped; for good puddle, when properly set and hardened in the centre of a bank, is so compact as not to be liable to be abraded or suddenly worn by a current of water. In case of the breaking or slipping of a bank, so that a considerable and wide breach is formed, and still increasing, it is a good practice to drive in two rows of common fold hurdles, at a foot or less apart, lashing the same well together by cords, and securing them by strong stakes drove down behind them, and if the stream of water be deep through the breach, it will be necessary to drive other long stakes obliquely into the ground, and securing their tops to the hurdles and upright stakes by laps of cord, that these last may act as struts to prevent the whole being borne away; into the cavity between the hurdles; straw or stubble should then be put and trod down, beginning at each end and working towards the middle, in order to prevent the current being turned, with fresh impetuosity, against the sides of the breach; such a dam as this will prevent the loss of any considerable further quantity of water, and will render the water stagnant, so that a row or more of pile-planks can be drove to cut off the connection with the breach, which can then be emptied of water, the hurdles and straw removed, and the reparation begun, with proper puddle-ditches for its security, as before described. At the famous Dagenham breach of the embankment of the *Thames*, dove-tail, or plank-piles were used, we are told. It will be necessary to defend many places of the banks of a canal that are obliged to be unusually steep, as in the approach to a bridge or lock, a wharf, &c. with a facing of planks, called *camp sheeting*; this consists of strong piles driven into the bottom of the canal, with the proper inclination, with horizontal pieces, or land-ties to their tops, on to which piles found and durable planks are spiked. In some places, owing to the accidental or unavoidable admission of very thick water into a canal, or in more cases by the ordinary deposit in length of time, the canal will become choked with mud. In these cases a machine with buckets, like a chain pump, to scrape the bottom of the canal, and afterwards discharge the load of mud into a barge, might be used, such a machine, worked by horses, being now in use in the *West India Docks*. See also *Walker's Lectures*, 4to. p. 35. The late Mr. Brindley, we are told, contrived a plan for the purpose of clearing the docks at Liverpool from mud.

By neglect it will sometimes happen in canals, that *Weeds* grow up from the bottom, and form an unsufferable impediment to the motion of the barges; and this is almost unavoidably and generally the case in river navigations, if constant care is not used to tear them up, or cut them down. On the great *Ouse*, and other fen rivers, a machine has been long in use, called a *beaver*, for tearing up strong weeds by the roots.

About the year 1796, the *chevalier Bentancourt Molina* presented to the *Society of Arts*, a model of a barge, having a windlass in its stern, which gives a circular motion to a pair of knives or scythes, or a lever giving an alternating motion to knives for mowing off weeds close to the bottom of a canal, in which the barge is to float, or on the sloping sides of the canal; for which purpose, the knives can be made to revolve at any depth below the surface of the water, and either horizontally, or inclined in any angle; this model may be seen at the society's house in the *Adelphi*, and a description and view of it will be found in their *Transactions*, vol. xiv. p. 345. or *Repertory*, VI. 169. In most winters it happens, that an ice not more than an inch or an inch and half

thick, continues for a considerable length of time on canals, and other stagnant waters; this, or even a less thickness of ice is sufficient to stop the trade upon canals, unless the ice is broken; and, for this purpose, it is advisable, every morning of a frost, unless the ice should be found more than usually thick, and the frost increasing, and likely to continue, to break the ice on each pound; this is usually and effectually done by a strong and square headed barge, whose sloping or projecting head is covered with strong iron plates. One of these barges being drawn along the canal, and into each lock, by several horses, has a constant tendency to rise up upon the ice, and thereby breaks it down before the barge: about the lock-gates it will be necessary to break the ice by stamping with the end of a pole. Mr. *Symington*, whose barge, with a steam engine in it, to propel it along, and tow other vessels, we have lately mentioned, has provided the head of his barge with stampers, to be worked by the engine, for breaking of the ice before it, in frosty weather.

Leaks in a canal may sometimes be stopped without emptying the water, if the depth will permit it, by preparing good puddle in a flat-bottomed dirt-boat or flat, and dropping the same in spadefulls equally over the surface, and when a certain length is done, raking the same about with a rake, with short teeth to join the pieces together, and level the bottom. The difference in specific gravity, in different loams and carths, is so considerable as to make some of them much more proper for the lining and facing of a canal than others; the heaviest that can be found should be used when leaks are to be stopped, and the water remain in the canal as above. We have passed along the branch of a canal on a chalk soil, where the lining of the bottom was so light, that the motion of the barge stirred enough of it up into the water, which was before nearly clear, to make it almost as white as milk behind us; this light stuff has since been taken out, and a substantial lining and facing of proper stuff brought in barges for the purpose, and laid on the bank before the water was let out, has been applied, by an able engineer, who succeeded those of too different a description who constructed this very leaky branch.

Some *implements* and machines are used in the making or working of inland navigations, which we have not had occasion yet to mention or describe. In every considerable work it will be necessary to erect rolling-stones for grinding and preparing of the cement or mortar that is to be used in the water-works. At *Worley*, on *Bridge-water's* canal, the power of a water-mill is applied to turning several pair of large stones on edge, like those used by tanners, gunpowder-makers, &c.; in some of these the stones rolled round on a fixed stone, in others a large cast-iron flat pan, in which the materials to be ground were put, was turned round under the stones, which were thus made to revolve round their own fixed axis on the materials. What appeared singular in the process at this place was, that the lime and other ingredients were ground with water for a long time, in the state of thin mortar, which was then removed into cisterns to dry, and before the same was become too hard, it was cut out by a spade, into lumps of about half a cubic foot each, and heaps of them were preserved in a store-room, where they became quite dry, and as hard as chalk, or harder, for use at distant periods of time, in the repairs of the walls and works under water. At the *London* and *East India* docks steam-engines, of twenty horse power in one case, were used for grinding their cement; but the pozzolana, lime, and other ingredients are here mixed and ground together in due proportion in a dry state (as *Parker and Co.'s* patent Roman cement is done), and it is not wetted, but carefully preserved

from moisture, till a very short time before it is to be used in the walls, &c. See the article *ROLLING-STONE*.

The *driving of Piles* is a very considerable business in many large concerns; at the entrance of the *London Docks* a steam-engine was erected for driving the vast number of piles which were required for the coffer-dam. Mr. S. Bunce contrived a very simple and effective kind of pile-driver, to be worked by men at a winch. Mr. Harvey contrived a double pile-driver, which is described in the *Transactions of the Society of Arts*, vol. xii. p. 337. The horse pile-driver contrived by M. Vauloue cannot, from the almost innumerable models, plates, and descriptions which have appeared of it, since the building of Westminster Bridge, be unknown to any of our readers. Mr. John Fould contrived a machine, and presented a model of it to the *Society of Arts*, (see their *Transactions*, vol. xiii. p. 280) for cutting off the tops of piles, after they have been drove, beneath the surface of the water. See the article *PILES*.

Some of the navigator's tools and implements, as barrows, horsing-blocks, grafting-tools, shovels, and scrops, we have represented in *figs. 48 to 52, Canals, Plate VII.*

Cranes for the hoisting of goods will be required on the wharfs of canals and rivers. See our article *CRANE*.

On the *general management*, and office department, of a canal concern, it is unnecessary to enlarge. The committee with which the conduct of it is entrusted will, without doubt, direct their attention to those various circumstances on which its prosperity depends. Accordingly, they will appoint proper officers in the several subordinate departments, and give them such instructions for the regular discharge of their duty as occasion may require. It may not, however, be improper to suggest, that the canal committees should direct their resident engineer to establish proper rain and evaporation gauges at several lock-houses upon the line, to be kept by the lock-keepers, and registered daily or weekly with great care: these observations, preserved in the company's books, or, what would be better, published in some of the magazines, would prove of great advantage to science, and to canal undertakings in general. In canals of considerable length, particularly if some parts of them are indifferently and variably supplied with water, or leaky, it will be right to fix gauges or graduated rods on each upper lock-gate, that would shew at all times how many inches depth of water there is at the time, in the shallowest part of that pound; and to cause the lock-keepers to mention the same at the foot of the printed permits or pass tickets, that the toll-clerks should give to every bargeman who passes, containing the number and description of each barge, and the description and weight of its loading; these, transmitted regularly to the toll collector, would enable him, or some other person, to keep for the information of the committee, a register of the daily state of each long or leaky pond of water; at the same time that the lock-keepers, toll-clerks, &c. at each extremity, and on different points of the canal, would always be acquainted with the state of the water, and the loading which a barge could pass with at every particular place; and could inform bargemen; for want of which knowledge great delay and expence are often incurred, in dry seasons, by setting off with more lading than can be carried through, for want of a sufficient depth of water, and part of the same is obliged to be left on the road, or taken into other boats. All the regulations contained in the act, for working of the canal, and such by-laws as the committee may see it necessary to make, for regulating the conduct of the bargemen and others on the canal, should be printed, and stuck up at every wharf on the canal, and in every toll-clerk and lock-keeper's house; and all the company's agents and servants

should be strictly enjoined to notice every breach of laws and regulations, not by altercation with the offenders, but by immediately noting down in writing the exact and true particulars of the time, place, and name of the offenders and bye-standers or witnesses, &c. transmitting the same immediately to the committee, and preserving a copy thereof themselves: and, though we are far from recommending severity in punishing on these occasions, yet a system of this sort, by shewing the offenders that the committee would always be prepared to proceed against them, would, in most instances, especially if the parties were written to, to threaten them, go a great way to prevent the same parties or others from offending again.

Tonnage Tables, fully and explicitly stating the toll or tonnage payable to the company, on goods or articles of every different kind, or on different parts of the line, if, as often happens, these vary, should be printed and stuck up on all the wharfs and toll-houses, for preventing all doubts or altercations between the company's servants and the traders. At some convenient place on the line of the canal, a *weighing-house* should be prepared, consisting of a dock under cover, large and deep enough to contain the largest vessels which are to navigate the canal; this dock should be furnished with a draw-gate to let down, or doors to shut, when an empty barge has entered, in order to render the water quite still within the dock. Cast-iron or leaden weights of 2 cwt. each should be provided, and a crane to hoist the weights readily in or out of the barge, and place them in any part of the same, so as always to load her evenly. To this weighing-house, the act or by-laws should require every barge to be sent, having the name thereof, and the owner's name and residence previously painted on the stem of it, before it is allowed to trade on the canal: the empty barge being arrived in the dock, the gauging-master fixes four small plates of iron, each containing the number that this barge is in future to be distinguished by, two on one side, and two on the other, against the gunwale, near the head and stern. These plates are all fixed at the same distance from the surface of the water, when the barge is empty; this distance, in inches and tenths, is entered into the gauging-master's book, under the number of the barge, name, owner's name and residence, date, and other particulars; two tons of weights are then hoisted into the barge, and regulated until the distance from all the four plates to the water's surface is the same, which distance in inches and tenths is also entered in the book against two tons; two tons more of weights are then hoisted in and adjusted, and the height of the number-plates above the water is taken and entered against four tons as before; these operations being repeated until the utmost lading of the barge is on board, when the weights are taken out again, and the barge removed from the dock. For measuring the height of the plates at the Paddington weighing-house, a tin tube is used, that is furnished with a float moving freely in it, to mark the surface of the water, which carries a light stick graduated to inches and tenths, to show the height of the number-plate against which it is applied. At every toll-house on the *Grand-junction* canal similar floating-rods are kept, and to every laden barge which passes this gauge is applied against the number-plate, at each end, and to those on the other side, if the barge appears to heel at all to either side. If the dry inches and tenths shewn by the gauge, between the number-plate and the water's surface, are different, they are added together, and divided by the number of them for the mean height. It is the business of the gauging-master to calculate, from the particulars entered in his book, of each barge as above, the weight to the nearest of $\frac{1}{4}$ of a ton, which answers to every inch and

tenth of an inch, of the dry inches shewn as above by the gauge; the number of the barges are applied in a regular series, in the order in which they come to be gauged; and a book, containing a table for the tonnage on board, answering to every dry inch and tenth, as above, is calculated, and a copy of each is in the possession of each toll-clerk, by a reference to which, he fees and enters in his toll-book, and in the pass-ticket or permit, the number of tons and quarters for which tonnage is to be paid to the company. On a great number of canals the practice is different; the gauging-master prepares four slips of copper or lead, about $\frac{3}{4}$ of an inch broad, and $\frac{1}{8}$ thick, and stamps thereon at every division answering to two tons, agreeable to the observations entered in his book, and between these strokes are drawn to mark the intermediate tons and quarters of a ton. These plates he fees carefully nailed on to the sides of the barge, under the number-plate; by help of which the toll-clerk, and the bargeman also, can at any time see the tonnage on board, by the place on the plates cut by the water's surface.

Most acts contain a provision respecting barges occasionally navigating a canal, or any others where reason appears to the toll-clerk to suspect a deception or fraud, for requiring the bargeman to give an accurate account of his lading on board; which if unsatisfactory, the toll-clerk may take such barge to the nearest wharf where accurate scales, steel-yards, or engines for weighing goods are kept, and there have the cargo unloaded and weighed; which expence, as well as a penalty, the bargeman is made to pay, if he had refused or neglected to give an account of his lading, or if his account so given shall prove below the real weight of the goods. New barges are usually indulged, in two or three voyages, before they are gauged, in order the better to suit the bargeman's and gauging-master's convenience for doing it, during which they are subject to have their goods weighed, as they also are, whenever they have different goods on board, liable to different rates of tonnage, and do not give a satisfactory account of the weight of each.

In many acts there are clauses inserted to prohibit the planting of trees in the canal-hedges, or on its banks, as there are also in others, for restraining the company from erecting any houses or buildings on the banks of the canal, except certain specified public wharfs, unless for the immediate use of the canal. A clause will be necessary, to punish persons who are found throwing ballast or any kind of soil overboard or into the canal, by which it might be choked up: it will also be requisite, strictly to prohibit the throwing of loose stuff, as chalk, gravel, sand, &c. by means of shovels, from heaps or barrows on the bank, into any barge, unless a broad and close stage of boards was first laid to catch the stuff, which will unavoidably scatter, and to prevent its falling into the canal.

Necessary tackle should be kept in readiness, for weighing up such barges that are sunk, without delay, on account of the total interruption that such will often occasion to the navigation. Where a sunk barge lies so that another barge cannot be floated on each side of it, the following method may be adopted: chains should be looped round the sunk barge and hooked, having four ends of sufficient length proceeding from near the four corners of the barge, two empty barges should be brought, one to each side of the sunk one, and strong beams of timber be laid across each of these barges, and the space between them; water should then be admitted into each of the barges by their plugs, to sink them almost to the water's surface, the plugs should then be put in, and the four chains be fastened tight to the cross beams, when a pump should be used in each of the barges to throw out the water, and as this is accomplished,

if the chains are properly fixed, the barge will be buoyed up, often to the surface of the water, so that she may be freed by pumping her; if not, she must be shoved along, suspended between the light barges, to some strong crane, where she can be further assisted, or into some dock or shallower place, where she can be relieved by a repetition of the same process.

Several further *Regulations for working of Canals* require yet to be mentioned: They are such as relate to the penalties that should be provided in the act or by-laws for preventing bargemen from taking in above a certain weight, adapted to the size of their boat and the depth of the canal; and also for preventing such boats from damaging the lock-sills or bottom of the canal, or sticking fast to the interruption of other boats. The nature of the lading and the manner of disposing it in the boat, so that the sides of the bridges, &c. may not be injured, should be duly attended to. Penalties should be provided to punish those bargemen who suffer their boats to strike against any of the locks or bridges, or those who suffer their barge to lie either for unloading or any other purpose, so as to obstruct the passage of other boats. In some acts this penalty is fixed, by the hours that such interruption continues, and at an increasing rate. Boats left at wharfs or other places, on or by the line of the canal, should be moored at both their ends. Bargemen should be prohibited from fishing, or having tackle for such purpose on board. It should be provided, and made known by the by-laws, that barges or vessels going one particular way on the line, and on each of the branches, should give way for those they meet or have occasion to pass; and on narrow canals or branches, it should be provided, that when two barges that are meeting each other first come in sight, or one of them hails the other, that which is nearest to a passing place, shall stop at or go back to the same to let the other pass. Common trading barges and vessels, and all others, should be prohibited from passing any locks or moving along the canal except in the day-time, and for this purpose it is usual to divide the months of the year into three or four portions, and to specify the hour both morning and evening in each, between which the canal is to be open. Light boats, for the conveyance of market-goods, parcels, &c. are allowed on some canals, as the *Grand Junction*, to pass on during the night, their owner paying a specified sum for a licence for such privilege, engaging to employ the most careful and experienced boat-men, and to make good all damage which such boats may do to the works of the canal, or to the barges or property of other traders. Mr. *Thomas Pickford*, the great waggon proprietor, has substituted boats in place of many of his waggons, and which travel night and day, and arrive in London with as much punctuality from the midland and some of the most distant parts of the kingdom, as the waggons do.

As few of the tunnels are constructed wide enough for two wide barges to pass each other therein, it may become necessary in such cases, where the tunnels are long, to establish an overseer at each end of the tunnel, where a basin of sufficient dimensions for several boats to lie and pass should be provided, to suffer no barge to enter at either end for an hour, or other period, or until the last boat from the other end is come out, to prevent wide ones meeting others in the tunnel. If the number of wide boats be very small in proportion to the narrow ones, the periods for the entry of narrow boats may be oftener repeated, and wide boats might, in extreme cases, be only suffered to pass the tunnel between the two basins after dark in the evening, when the other boats are lying still on the canal.

Gentlemen's pleasure-boats, and narrow short husbandry-boats, for the use of the occupiers of the lands on each pound, are often allowed at very easy rates, if not quite free of tolls; and sometimes such, as well as any other boats laden with manures and road-materials, are allowed to pass the locks on the same conditions, at such times only as the water runs over the lock-weirs, or is within a very small quantity, as half an inch, of that height.

The regulations of vessels *passing the Locks* are usually very explicit in canal-acts, that boatmen may not suffer the water to remain in the locks longer than is necessary for their boats to pass; that every boatman in going down a canal, shall, previous to his bringing his boat into any lock, shut the lower gates of such lock and the cloughs thereto belonging, before he shall draw the cloughs of the upper gates; and, after he shall have brought such boat through the lock, he shall then shut the upper gates before he shall draw the cloughs of the lower gates, and in going up the canal, such boatman, as soon as he shall have passed his boat through the lock, shall shut the upper gates of the same, before he shall draw the cloughs of the lower gates, unless there shall then be a boat coming down the canal, in sight of the said boatman, in which case the lower gates of the lock shall be left shut, and the upper gates shall be left open; and in all dry seasons, or where there shall be a scarcity of water in the canal, the boat so going up (if within sight of a boat so coming down,) and at a distance not exceeding two hundred yards below a lock, shall pass through such lock before the boat coming down, and then such other boat shall come down into the lock; and if there shall be more boats than one, below and above any lock at the same time, in any such dry season, within the distance aforesaid (which distance shall be distinguished by a post set up for that purpose), such boats shall go up and come down at such lock *by turns*, until all the boats have passed, by which means one lock full of water may serve two boats. A penalty should be provided against any bargeman or other person, who draws the cloughs, except while barges are passing as above, or for leaving any clough open; as also against any lock-keeper or other servant of the company who gives undue preference to any boatman in passing the locks, or in unloading his barge at the public wharfs. Posts should also be provided by the side of the locks, for strapping or stopping the velocity of boats before they enter the locks, and penalties ought to be provided against the winding of their rope or strap round any part of the gates or lock, in order to stop a barge, except the strapping-posts before mentioned; after all, the engineer should be careful to form the heads of the gates, and all other projecting points about his locks, of such a sloping or wedge-like form, that the rope would have no hold upon them, but slip off. A clause should always be inserted in the act, for making master boatmen answerable for all damage done by their servants, giving them, however, the right of recovering from their servants in all cases of wilful damage or neglect. On some canals it is usual, for the masters to hire their men by the ton of goods which they navigate certain distances, instead of paying them by the day for their time.

For some time past, the rate of *Freight* on some canals, over and above the company's tonnage, has been two-pence per ton per mile, for unperishable goods, three-pence per ton per mile for perishable goods, and four-pence halfpenny for bulk goods. In times of distressing scarcity, like those of 1795 and 1800, the committees of several canals, have permitted the passage of imported grain, going towards the interior of the country, toll free, with the laudable intention of lowering its price to the community.

The *Principles of constructing River Navigations* require some further notice in this place, in addition to the particulars which we have already had occasion to notice respecting them in this article.

Mr. Thomas Telford has given an account of the navigation of the river *Severn*, which is printed in *J. Pymley's Agricultural Report of Shropshire*, pages 284 and 317, from which we shall collect some particulars, and remark thereon, with the view of shewing by an example, what are the nature and extent of the difficulties which navigation has to contend with, upon natural rivers. This justly famous river is navigable up to Welchpool, a distance of 155 miles by water, from the mouth of the Bath *Avon* river; the extreme branch of this river may be traced for about 45 miles above Welchpool, to Plinlimmon Hill, and numerous other branches extend for great distances into the country on both sides; the whole of this great length of river navigation was till lately unimproved by art, it having no locks, weirs, or other erections throughout its whole length for surmounting the numerous shallows and irregularities, which the current over variable *strata* had formed in its bed. The first, or lowest 42 miles of this river, extending to the city of Gloucester, are very wide for great part of the way, and have a most rapid tide; but the last 28 miles are so crooked, that ships are said to be often several days in passing it; on which account, a grand canal, calculated for vessels of 300 tons burthen, was in the year 1793 projected and begun, between Gloucester and Berkley, of 18½ miles in length, for avoiding these 28 miles of the river. From Gloucester to Worcester the distance is 30 miles by the course of the stream, the rise in this length being 10 feet, or at the rate of 4 inches in a mile; from Worcester to Stourport the distance by water is 13 miles and the rise 23 feet, or at the rate of 1 foot 9 inches per mile; from Stourport to Bridgenorth it is 18 miles, and the rise 41½ feet, or 2 feet 4 inches per mile on the average; and, from Bridgenorth to the New Town at the junction of the *Shropshire* canal, called *Coal-port*, the distance is about 7 miles, and the rise about 19 feet, being a rate of about 2 feet 8 inches per mile. It was, we believe, that excellent and public-spirited individual, Mr. William Reynolds, the founder of *Coal-port*, who caused an account to be daily registered, of the depth of the stream in the bed of the *Severn* river at that place, between the 7th of October 1789, and the 23d of December 1800, of which Mr. Telford has given us the particulars, except on 12 occasions when the river had overflowed its bounds and covered the usual marks, on Sundays during some part of the time, the intervals of frost in which the river was frozen over, and for three short intervals, when unfortunately the experiment was by some accident suspended. These valuable materials we have examined with considerable care, and shall present our readers with some results therefrom, that will be of use in judging of the interruptions from floods, drought, and frost, to which river navigations are liable; and we do not apprehend that this river is more subject to them than the British rivers are in general, excepting those smaller ones like the Colne, the Wand, and others, which are supplied principally by spring-waters. During all the months of *January*, in the above period of 11 years, ending the 6th of October, 1800, the river was twice overflowed, (2d Jan. 1790, and 27th Jan. 1800,) and exceeded, we should suppose, the depth of 16 feet, that being the greatest depth at any time recorded; and several times, when no depths are inserted to the great floods, it is stated in the table that the water was above all the marks: besides these, there were 32 smaller floods, or times when the water had risen, and was falling again for some days after; the highest of these had a

depth of 13 feet (5 Jan. 1790,) the lowest 4 feet, and the mean of the whole of these floods is $7\frac{1}{2}$ feet. In the months of *February*, there were two of these overflows, one of which (11 Feb. 1795,) followed a frost, and continued for 5 successive days: 19 floods, the two highest of which were equal (17th and 20th Feb. 1799,) to 12 feet; the lowest that we have noticed was 4 feet, and the mean depth of water in all of them was $7\frac{1}{2}$ feet nearly. In the months of *March*, the bounds were but once overflowed, and we have noticed 11 other floods, the greatest height being 9 feet, (17th March 1794,) at which it continued 7 days, and the lowest $4\frac{1}{2}$ feet, and the mean height of them about $6\frac{1}{2}$ feet. During the months of *April*, two overflows of the river are mentioned, the heights of 14 floods are recorded, the highest (5th April 1794,) 10 feet, the lowest $4\frac{1}{2}$ feet, and the mean $6\frac{1}{2}$ feet. In the months of *May*, but one overflow of the river is mentioned, (30th May 1792,) and 7 floods, the greatest depth of water at those times being $7\frac{1}{2}$ feet, (6th May 1797,) the least $4\frac{1}{2}$ feet, and mean $5\frac{1}{2}$ feet. The months of *June* produced no overflows, but 8 floods are recorded, the greatest $6\frac{1}{2}$ feet deep, (4th June 1797,) the least $3\frac{1}{2}$ feet, the mean height of them being $5\frac{1}{2}$ feet. The months of *July* produced no floods which overflowed the banks or marks; of the 10 that are recorded, the highest was 7 feet, (1st July 1797,) the least $3\frac{1}{2}$, and the mean of them $4\frac{1}{2}$ feet. During the months of *August*, the highest of the 19 floods, or highest waters that are mentioned, was 11 feet, (19th Aug. 1799,) the least that we have noticed is 3 feet, and the mean height was $5\frac{1}{2}$ feet. The months of *September* produced 17 floods, the greatest $9\frac{1}{2}$ feet, (23d Sept. 1797,) the least $3\frac{1}{2}$, and the mean we find to be 6 feet nearly. In the months of *October*, one overflow took place (10th Oct. 1789,) and 24 other rises of the water or floods, the greatest being 10 feet, (10th Oct. 1799,) the least $4\frac{1}{2}$ feet, and the mean $6\frac{1}{2}$ feet. In the months of *November*, one overflow is mentioned, (1st Nov. 1792,) 28 other floods, the greatest of 11 feet depth (8th Nov. 1799,) the least $4\frac{1}{2}$ feet, and the mean $6\frac{1}{2}$ feet. Lastly, in *December* in the several years, two overflows of four days each are recorded, (1st Dec. 1791, and 2d Dec. 1794,) the number of floods being 29, the greatest height 16 feet (5th and 7th of Dec. 1797,) the least 4 feet, and the mean we find to be $7\frac{1}{2}$ feet in height.

From the above it results, that the *Severn* river at Coal-port is subject to about one overflowing of the banks annually, besides about 20 lesser floods, varying (in 11 years,) from 16 to 3 feet in height, the mean height of which is about 6 feet 7 inches. It also appears, that the greatest floods, and those occurring the oftenest, are in December and January; that the fewest floods happen in May and June, and are the least in height in June and July.

We have now to mention the results of an examination for the lowest states of the stream of water in the river, in the above period. In all the *Januaries* the depth never was less than 1 foot 8 inches, on one of the two such occasions (13 Jan. 1793,) it continued so for three days. In *February* it never was but once so low as 1 foot 8 inches, and then (26 Feb. 1797,) it continued so for three days. In the months of *March* we have noted ten lowest states of the water, four at 1 foot 8 inches, four at 1 foot 6 inches, and two at 1 foot 5 inches (19 and 25 March, 1797,) the mean of these low-waters being 1 foot $6\frac{1}{2}$ inches. In the months of *April*, ten low-waters were observed, the greatest 1 foot 8 inches, and least 1 foot 2 inches (30 April, 1796,) the mean being 1 foot 5 inches nearly. During the months of *May*, eighteen low-waters occurred, the greatest being 1 foot 8 inches, and least 1 foot only, and which continued for seven successive days

(29 May to 4 June, 1795,) the mean being 1 foot $5\frac{1}{2}$ inches. In the months of *June* we notice twenty-three lowest states of the water, varying from 1 foot 7 inches to 1 foot, which last was the depth at four different periods, (two of which amounting to twelve days were in June 1791,) the mean of these is 1 foot $3\frac{1}{2}$ inches nearly. In the months of *July* the low-waters were thirty-one in number, varying from 1 foot 8 inches to 11 inches, (14 and 15 July, 1794,) the mean 1 foot $3\frac{1}{2}$ inches. In the months of *August* there appear to be thirty-three low states of the stream, the highest that we have noticed are 1 foot 8 inches each, and the lowest only 9 inches! (5 and 16 August, 1800,) the mean 1 foot 4 inches. During the months of *September* the low-waters were twenty-four in number, the greatest 1 foot 8 inches, and least 11 inches, (7 September, 1796,) the mean being 1 foot 4 inches. In *October*, in the different years, were twelve low-waters, from 1 foot 9 inches to 1 foot 1 inch in height, (3 and 4 October, 1791,) mean 1 foot 6 inches. *November* produced only three low states of the water, 1 foot 10 inches and 1 foot 8 inches, (8 November, 1791, and 11 November, 1796,) mean 1 foot 9 inches. Lastly, in the months of *December* four low-waters are recorded, 1 foot 9 inches, and 1 foot 7 inches, (9 December, 1793, and 20 December, 1799,) the former continuing for three days,) the mean of these being 1 foot 8 inches.

From the above it appears, that the *Severn* at this place is subject to between fifteen and sixteen low states of the water annually, and each of them will be found of much longer continuance than the floods are; the lowest having 9 inches only in depth of water, the greatest that we have here taken out being 1 foot 10 inches, and the mean of all such we find to be 1 foot $4\frac{1}{2}$ inches. It also appears, that it is not oftener than once in two or three years on the average, that a low state of the water (1 foot 8 inches) occurs in any of the four winter months, November, December, January, and February; that June and July are subject to the lowest waters, and July and August to the most frequent rises of the water; the reason of this last circumstance appears to be, that in this low state of the water, and when the breadth of the river is the least, the effect of almost every partial thunder, or other heavy shower, on any of the branches of this river, is visible in the same at Coal-port, which waters could not have been noticed, when the stream was so many times larger, as it generally is. We observe, that the mean height of the low-waters in both August and September is 1 foot 4 inches, (the general mean of all the months being 1 foot $4\frac{1}{2}$ inches,) and if the mean of the six summer months, from April to September inclusive, be taken, it will be found almost exactly 1 foot 4 inches: what is also remarkable, the river has been found to be far more stationary at this particular height than any other, since, on thirty-five days, beginning with the 25th May, 1793, it never varied from that height, on eleven days, beginning 15 June, 1795, and on ten days, beginning 15 July, 1795, it also ran steadily at that depth; while it never remained but twice at any other height for ten days together, viz. fifteen days, beginning 23 September, 1795, at 1 foot 2 inches; and ten days, beginning the 14 August, 1795, at 1 foot 3 inches depth: but twenty-six instances occur in all the eleven years, of the water remaining for more than four days together at any other height than 1 foot 4 inches, several of these being very near that height; and, indeed, instances of a stable height are so rare, that often for months together no two following days are to be found alike. From the above we may, we think, with tolerable safety infer, that 1 foot 4 inches is the depth of the stream of water in the *Severn*, at Coal-port, 45 miles, below the upper end, and 110 miles

above the lower end of its navigation, arising from springs; the height of water above this being principally occasioned by the rain, which so frequently falls in one part or other of the Welsh mountains and hilly tracts, whose running waters this river receives. Seven times in the above eleven years the *Severn* was frozen over at Coal-port; on one of these occasions the river continued locked up for 20 days, beginning the 11th January, 1795; the next longest interruption, from the river being frozen over, was nineteen days, after 27th January, 1798; fourteen days, after 1st February, 1799; fourteen days, after 20th December, 1799; thirteen days, after 2d December, 1796; eight days, after 22d December, 1796; and, lastly, three days, after 2d January, 1795. These amount in all to 100 days, or to about nine days of total interruption from ice annually, supposing they had happened regularly; but it appears above, that in only four of the winters in this period was the *Severn* froze over at Coal-port, viz. in that of 1794-5, for thirty-two days; that of 1796-7, for twenty-one; in that of 1798-9, for thirty-three days; and, in that of 1799-1800, for fourteen days; or, for twenty-five days on the average, in each frosty winter, while seven winters passed without such interruption. The water was generally low (in one instance only 1 foot 7 inches,) when the *Severn* became froze over as above, occasioned, we apprehend, principally by the rapid and great evaporation which will be found always to precede and accompany a frost; and by the frost having set in and retarded the fall of the waters, in the open and exposed parts of the country which supplies the *Severn*, before the same was become intense enough to cover that river with ice, in so deep and narrow a vale as at Coal-port.

Mr. Thomas Telford remarks, that the year 1796 afforded so striking an instance of the fluctuating nature of this river, that during the whole of that year, there were not two months in which barges could be navigated, even down the river, with a freight which was equal to defray the expences of working them; an interruption to trade that was severely felt by the great coal-masters and manufacturers of iron in those parts, in particular. The same intelligent engineer observes, when speaking of the *Severn*, "the inconveniences arising from the irregularities of the water have always existed in some degree, but they have been greatly increased by the embankments which have lately been raised to protect the low lands in Montgomeryshire, and in the upper parts of the county of Salop. Formerly, when the river had arrived at a moderate height it overflowed these lands to a great extent, which thereby operated as a side reservoir, and took off the top waters of the high floods; and these waters returning to the bed of the river by slow degrees proved a supply for the navigation, for a long time after the flood began to subside, but being now confined to a narrow channel, they rise suddenly to a great height, and flow off with more rapidity than formerly; whereby the navigation is at one period impeded by uncontrollable floods, and at another left destitute of a sufficient supply for its ordinary purposes." Besides the embanking of low lands by the sides of considerable rivers noticed above, another cause has been observed by us, for the change for the worse, which is well known to have happened to many of our navigable rivers, within the last 50 years; in which period, a great portion of the common-field parishes in England have been inclosed, and in the greater number of instances, new and straight brooks and water-courses have been cut therein, instead of the exceedingly crooked and serpentine courses which most of them had; these have had the effect of letting down the rain waters much more freely than formerly, from almost every branch of many of our eastern and some other rivers, and

have occasioned floods much more sudden and high than were probably ever before experienced; at Bedford, on the *Ouse*, we remember reading of two or three immense floods, within a few years past; such as would have effectually prevented the erection and growth of the fourth part of the town on its present site, if such floods had ever before prevailed; and the effects of these increased floods have been experienced in the fens, through which these rivers pass, by the continual necessity which has been found of raising their banks to prevent the water overflowing them, and filling the adjacent country. In the fens this remedy has been found adequate; and the evil might have been remedied higher up the same rivers, if attention had been paid to increasing the water-way under their bridges, erecting others in place of the numerous fords that on some rivers exist, and cutting off sudden bends in the course of the rivers; and above all, requiring the mill-owners to make more capacious flood-gates, to be opened on the first rise of water, in order that it may pass off by the channel, to prevent the valley being filled for a great distance above, and agriculture being interrupted or prevented, as it used to be in the smaller vallies above, before the brooks therein were straightened, or new ones cut. The same causes which have occasioned this increase in the rapidity and height of the floods, have, as observed by Mr. Telford, caused the quantity of water to be less in the rivers in the general; a circumstance which receives strong confirmation from an able pamphlet, said to be written by the late Mr. Wedgewood, in 1765, entitled "A View of the Advantages of Inland Navigation," wherein it is mentioned, speaking of the *Severn* river near to Coal-port, "that the lowest water that ever happens, in the driest summer, is never less than 18 inches, which is sufficient to carry vessels of 16 or 17 tons burthen at any time." We have seen above, that this river, since 1789, often runs with a stream no more than 16 inches deep for considerable periods together, and is frequently so low as not to have a foot depth of water in it, while instances of such extreme drought have been recorded, that the depth was reduced to 5 inches, or half what was formerly said to be its lowest state. The progress of agricultural improvements in the last age would have had a still more sensible effect, in producing a low state of the water in our rivers, after the sudden floods are run off, but for another, and contrary effect from the above, by which they are accompanied; we allude to the more general drainage and cultivation of the surface of the ground, by which it is enabled to absorb and take in so much greater a portion of every shower of rain than formerly, most of which water afterwards finds its way through land, or permanent springs, to the brooks and rivers, and prevents that very diminished state of them, which every dry season must now otherwise occasion. We may consider, that all land whose surface is wet, and in want of draining, is in that state as incapable of absorbing or retaining the rain waters, as the tiles of the roofs of houses, or the paved streets in a town are; and, that when that most essential of agricultural improvements, under-draining, has been applied, and the surface rendered fit for cultivation, that the whole of a large portion of the showers of rain, and a considerable portion of all of them, are absorbed and retained in the land, to be afterwards slowly given out, by the under-drains or springs, for equalizing the rivers. We were not fully aware of the great effects which a change to cultivation from a state of neglected common, has upon the absorbent powers of the soil, until viewing the improvements of the late excellent Duke of Bedford, in Crawley, in Bedfordshire, before mentioned.

In projected improvements upon any of our old river-navi-

gations; or in extending the navigation thereon above the tide-way, it is of importance to examine the state of the whole country, to which the river in question acts as a drain, to observe accurately whether cultivation, or the breaking up of lands, and the practice of draining have been going on, or are likely to be so in any considerable degree, within a reasonable period; as also to observe particularly the state and extent of the valleys and meadows, over which the waters are or have been spread in ordinary floods, and the probability of such being further prevented by straightening or enlarging the beds of the brooks and rivers, or embanking the courses of the streams; these, with the most correct information that can be obtained from different millers and others, who live on the banks of the river, or from scientific individuals, who have caused accounts to be kept of the height of the water, will be necessary data for determining the magnitude and nature of the works which will be necessary on the proposed navigation.

Mr. William Chapman, in his *Observations*, often before quoted, page 74, when treating of the canals of China, which are in effect but new channels for a part of the streams of their rivers, takes occasion to introduce some useful observations on the crookedness and unequal sections of rivers, and on the effects of shallows, weeds, and other impediments, upon the velocity and height of the stream, that we must reluctantly for the present pass over, referring the reader to our article RIVER. As an instance of the fall and velocity of large natural rivers we are told, that the Ganges for 60 miles, having the mean width of 3-; this of a mile, and depth of 15 to 20 feet, was found to have a fall, in a direct line, through the immense flats and rice-fields on its side, of 9 inches in a mile, but by following all the bends of the river's course, the fall was reduced to 4 inches per mile, and its velocity therein did not exceed 3 miles per hour. On ascertaining readily the velocity of streams of water, and comparing the same with theory, see *Nicholson's Journal*, 8vo. vol. iii. p. 32 and 87.

Mr. William Chapman seems to incline to the opinion, that locks may not always be eligible on river-navigations, and says (p. 87,) that "during the flooded state of rivers, all small falls are equalized, as they necessarily rise higher below than above a rapid; therefore I am far from saying, that running canals with a small fall are not, in many instances, eligible on the shores of great rivers; and that well devised stops, easily opened and closed, (not such as lift up like those described in China, nor open against the stream as gates,) are not sometimes preferable, to incurring the charge of locks. In other nearly similar instances where locks are eligible, their piers and gates alone, will be sufficient without any other floor or side walls, than a concave and battered pavement, continued through the bottom and up the sides of the space between the piers. The eligibility, and the particular construction of these works, will much depend on the nature and extent of the beds of the rivers, the difference between their low and flooded states, the height and also the permanency of their shores, and the quantity of floating ice.

The greater number of rivers through which new navigations are now required to pass, will be found occupied by mills, at shorter or longer distances from each other, according to the fall of the water in most instances; at the tail of most of such mills, will be found a large and deep pool, which the fall of water from the mill-courses and flood gates has torn and excavated, and a short distance below this pool a shoal or bed of gravel, or other matters, will in general be found, that would prove so expensive to remove, and would in general be so subject to accumulate

again by a further excavation of the pool from the increased fall of the water into it, that it will in general be the cheapest and most effectual way to begin a new cut for the navigation below this shoal, and continue the same up by the side of the pool to the bank of the mill, wherein a pound lock must be constructed, either of timber or masonry, for gaining the ascent to the mill-dam or upper pound. In rapid rivers subject to great floods, the utmost care and attention of the engineer to the construction of such works will be necessary, to prevent their being demolished by the first flood perhaps after their erection. Where mills do not intervene, and rapid and of course shallow places occur in the bed of the river which is to be made navigable, a side-cut must be begun from above such shallow, and if practicable at the beginning of a considerable bend of the river which the side-cut may cut off and shorten; in continuing this side-cut downwards towards the place where the lock is to be placed, and the junction below the same is to be formed with the river below the shallow, care must be taken to conduct the side-cut, which is to be upon a level as far as the lock, as soon as possible across the flat meadows to the borders of the high ground, along which it should skirt, to the place of the lock, if this is practicable, on account of the width of the meadows; otherwise a counter-drain or parallel cut must be taken up from below the lock, as far as is necessary, on the land side of the side-cut, to drain off the water, and prevent a swamp or pond being formed above the lock and between the side-cut and the high ground, as is almost invariably done by the ancient mill dams on most rivers and streams: it is, however, with the utmost care and precautions that the counter-drain should be adopted, otherwise, in time of floods, when the meadows are overflowed, such a current would rush into and down the declivity of the counter-drain as to endanger the tearing thereof, and of the bottom and sides of the cut or bed of the river, into which it vented below the lock. We have seen large and expensive sluices erected upon and near to the vent of counter-drains circumstanced as above, of greater height than the top of the floods, which were found necessary to be built, and kept shut on the approach of a flood to prevent the action of the counter-drain, until the flood had subsided so far as not to overflow the meadows adjoining the counter-drain. Across the bed of the river at the most convenient place below and near the upper end of the side-cut, an opening-weir must be constructed, by which the water in the river can always be kept at a proper height for covering the shallows and bed of the river to a proper depth for the navigation; several of these opening-weirs have within these few years been constructed on the *Thames*, one of which near Windsor has been described and drawn by Mr. Zach. Allmatt in his *Considerations on the best Mode of improving the River Thames*, 1805, p. 22. It consists of several strong piles or posts driven firmly into the bed of the river at 20 to 25 feet apart, in a straight line across the river: the intervals between these piles are driven and nicely filled up with pug-piles, or dove-tail piles, as before described in this article; these last are afterwards sawed off straight and even with the bottom of the river, and have a strong and sound fill nicely fitted and spiked on to them, and into each of the large piles at its end; by this means the water is prevented from soaking or making its way, except through the rectangular openings between the several piles, which should be at least as high as the highest floods, and have their tops connected by strong cross pieces of timber bolted on to them; in these cross pieces, and in the fill below, a number of holes are prepared for placing at equal intervals as many upright pieces of wood, called rimers, with rebates in their sides,

for temporary gates to slide down in, and rest against; after these rimers are put in, a sluice or gate, with a tall handle to rest against the upper, or cross piece, is put in between each rimer; and, above these, another set of gates, called overfalls, with similar handles, are fitted, to be occasionally used in dry seasons, when none of the water is to be suffered to escape, except by the slide-cut and lock-paddles. In time of floods, all these gates, overfalls, and rimers, are taken away, by persons who go in a boat for that purpose; which operation, we are told, can be performed in three hours, and the water is suffered to take its free course through the openings: as the water subsides, a few of these gates are put in at a time, leaving the water its course through the others, until all of them are in, when on any small rise of the water, the same falls over the tops of these gates into the bed of the river below; when a greater depth of water is wanted above, the overfalls or upper gates are successively put in upon the others; these last being of such a height that the water can fall over their tops before it would overflow the meadows in case of its rising, and the men not attending or being expeditious enough in taking away the overfalls, and then the gates, if the progressive rise of the river should render it necessary. Mr. J. Plymley in his report before quoted, page 316, has given a plate of a weir of this sort for a river, which is called a gate sluice, with 17 gates, but we have looked in vain for any description or account thereof in his volume. In the *Thames* and several other rivers, *Jetties*, or *Weir-bedges* have formerly been made, for diminishing the width of the river below the several shoals, in order to make a deeper but narrower and more rapid current over the same, as is done, we are told, on the China canals; but the rapid and dangerous currents which these and the under-water weirs occasion, particularly in high water times, have been so justly and loudly complained of, that we trust the same will, ere long, give place to the slide-cuts, pound-locks, and opening-weirs, above described. The principles on which jetties are made to raise the water in rivers, and the mode of calculating their effects may be found in *Nicholson's Journal*, 8vo. vol. iii. p. 35.

For improving the navigation of rapid, confined, and variable rivers, like the *Severn*, Mr. Thomas Telford, in *Plymley's Report*, p. 287, has recommended the deepening of the lower part of the bed of the river in the shallow places, in order to equalize the declivity and current of the river: a very experienced engineer has suggested, that deepened shallows, without jetties or similar constructions, would soon be again filled up in many cases. In the higher parts, Mr. T. proposes to erect solid and durable weirs of masonry across the river upon the shallow places, with slide-cuts and pound-locks by the side of them, for the navigation; and the river when thus diverted, may, as he justly observes, be applied to many important purposes of machinery, and for irrigating of the meadows, which would thus be brought within its reach. There is no doubt but this method is practicable, and would ultimately answer well; but the expence would be very great of erecting substantial weirs, and making the banks of the slide-cuts, and walls, and gates of the locks, high enough to prevent the floods from breaking over into them, a condition which seems necessary, if barges are to be able to proceed at all times; the towing-path should also for the same purpose be made up with a regular sloping bank next the river, presenting no inequalities or projecting objects to catch or wear the towing-lines, so that its top or path shall be always above water. On a river which rises 16 or 17 feet or more, these works would be attended with a most serious expence and difficulty, particularly where cliffs rise almost perpendi-

a stream, unless great expence indeed was incurred to obviate it, would be subject to have its work interrupted by every large flood: the working of barges on a river with such cuts, locks, and towing-paths, as we have mentioned, would be attended with considerable difficulties; tall masts must be used for attaching the towing-line in dry-times to bring the line on a level, or nearly with the horses, and in floods it must be fixed lower down, or to a shorter mast: and, in such cases, the utmost care might not always be able, where the works are necessarily confined by rocky banks, to prevent barges from sometimes missing the entrance of the slide-cut, and being precipitated down the current over the weir, and being sunk. A towing-path, locks and banks of a less height, so that the floods would frequently cover them, besides their being totally useless in such times, would be liable to be damaged and washed away, (unless constructed in the most careful and expensive manner,) and the cuts and locks to be filled up in a great measure by sand, or gravel, in rapid rivers. Mr. William Reynolds set an example which has since been followed, on a great length of the *Severn's* bank, of constructing a towing path for horses, instead of the devious way over projecting rocks, loose sands, mud, and every other obstacle which the men who used, from time immemorial, to perform the slave-like office of hauling the barges along, were obliged to travel: we are not acquainted with the height of these new towing-paths, or whether they are at times, and how frequently, covered and useless by reason of the floods. Mr. Allnutt informs us, that one horse commonly tows a barge of 130 tons burthen down the *Thames* above Richmond, at the rate of two and an half miles per hour. While on the running canals of China, *fr George Staunton* observed a boat of a light construction, with only 14 tons lading, of eight feet width of floor, about 10 feet width of water-line, and 50 of extreme length, drawing two feet three inches of water, and sharp at the ends, dragged against a stream whose velocity was $5\frac{1}{2}$ English miles per hour; and, although there were 28 trackers, or men hauling at the line fastened to the boat, besides three men in the boat poling it on, it advanced only at the rate of $\frac{1}{4}$ of a mile an hour; although the channel was not materially contracted in either width or depth of water-way, in proportion to the section of the boat. Mr. Thomas Telford has (p. 288.) proposed another method of improving the *Severn* river, by collecting "the flood waters into reservoirs, the principal ones to be formed among the hills in Montgomeryshire, and the inferior ones in such convenient places as might be found in the dingles, &c. along the banks of the river. By this means, the impetuosity of the floods might be greatly lessened, and a sufficient quantity of water preserved to regulate the navigation of the river in dry seasons, and likewise to answer many other useful purposes, such as the forming ponds for inland fisheries, the supplying of artificial canals, and the watering of land. This, it is thought, might even prove the simplest and least expensive mode of regulating navigable rivers, especially such as are immediately on the borders of hilly countries." An engineer of the first reputation in his profession (Mr. Rennie,) intimates, that after what has been said respecting the excess of flood water in the river *Roch* above the ordinary supply, the idea of correcting the floods of the *Severn* by reservoirs, must appear to be ridiculous. Mr. William Jessop, on another occasion already referred to, says, that the rivers may be rendered nearly uniform throughout the year by reservoirs.

The old clumsy stone or brick bridges upon rivers are a very principal interruption to the navigation thereon, by preventing the continuation of the towing-path in a place where it is generally the most wanted to surmount the rapid

bridge; the masts of vessels are also obliged to be struck. These circumstances recommend the more general imitation of the spirited individuals near Coalbrook-dale, who have there erected two cast iron bridges over the *Severn*, whose single and capacious arches remedy these evils. We have already spoken of them under the article *BRIDGE*, and in the present one, and therefore proceed to the only remaining subjects that at present occur to us, relating to the deepening of rivers: the *leaving of ballast*, or taking up of sand, gravel, or other loose or soft matters from the bottom of rivers, is usually performed by a strong pole, having a flat ring or hoop of iron fixed on its end, to which a strong leathern bag is fastened, like what is called a landing-net among fishermen; or for taking up gravel only, a fine and strong net is used instead of the leathern bag; the edge of this hoop is made sharp, so as to strike into the bottom, when a man pushes it down by its pole; near to this hoop a rope of considerable length is fastened, which is held by a man that stands at the head on the gunwale of a barge at anchor, while another man at the stern strikes the hoop and bag into the bottom, the man at the head then hauls at the rope to drag the bag along and scrape the bottom, while the other man shoves down the pole to which it is attached, until the bag is filled with sand, gravel, or other matters, which are wanted to be got up; the man with the rope then advances nearer to the other, and pulls up by the rope while the other does the same by the pole, and brings the bag over the side of the vessel, and empties its contents into the hold or room of the barge. If the bottom be hard, or the bag large, two or more men are employed to pull the rope, and sometimes a winch and roll on which the rope or chain winds, are used for dragging the hoop and bag along the bottom, and for hauling the same up to the surface, when the man at the pole finds that the bag is full, and begins to pull instead of push by the pole: this is the employment at Woolwich of a great number of convicts, instead of their being transported. Solid matters or rocks when they happen to want excavating, below the level that the water can be drawn off to, or the ebb of the tide, seem to require all the skill and resources of the engineer. Near to the entrance of the new *East India Docks*, in the way of ships in the river *Thames* at Blackwall, is a rock or large stone of exceedingly hard siliceous pudding-stone, consisting, as we have been informed, of the hard small chert pebbles which abound so much near London, embedded in a cement still harder than themselves; detached blocks of which pudding-stone are by no means uncommon in the London *strata*; this rock is so hard that no tool is capable of boring it, and though for some years past the committee for improving the port of London have been occasionally advertising for persons who were willing to undertake or contract for removing the upper part of this rock, about 40 feet in length and 30 in breadth to the depth of about 18 feet, yet the rock still remains. The conduct of this business is now, it is said, committed to Mr. *Jessop*, an able engineer; and we hope soon to hear of this dangerous impediment being effectually removed.

Having now given the principles and practice of canal-making, and of river-navigations and rail-ways, as forming one great, compound, and connected *System of Inland Communication*, we now proceed to give a concise account of all the different establishments of this kind in the United Kingdoms. This part of the present article, although far short of the degree of perfection which we were desirous of giving it, has been attended with great labour, in research for the scattered, and often scanty materials, that are to be found respecting many of these undertakings, which will ever remain as stupendous monuments of British enterprize and spirited exertion.

Respecting the method of arrangement, we found it inexpedient to follow those who have attempted to give an account of some of these concerns, in the order of time in which they were projected or begun; because so many of them, in distant places, were projected at the same periods, while some were quickly begun and completed, and others remained a great while in hand.

The great length of some of these works or undertakings, the shortness of others, their various directions and their general and multiplied interfections with each other, rendered any geographical arrangement of them, as from north to south, or otherwise, equally difficult and improper. We trust, therefore, that our readers will approve of the plan which we have adopted, of giving the whole of these undertakings, rivers, canals, rail-ways, &c. in one alphabetical series, arranged according to the *incorporate, or parliamentary name* of each, where the same are under special acts of parliament. And, as many important lines of canal have been surveyed and described, but never since were executed, we have thought it right to preserve the memory of many of such, by giving them a place in the regular series, but printing their titles in *Italics*, to distinguish them from the works existing or now proceeding with, which will be printed in small capitals. Our principal aim has been to exhibit, as concisely as possible, the principal features of each concern, and to trace its connecting points with all the other adjoining ones; by the help of which, it is hoped that our readers may be able to trace out and comprehend this great and unparalleled system of improved inland communication, which has, and will continue to operate so powerfully towards our national prosperity.

ABERDARE CANAL. This undertaking was begun under an act of the 33d of Geo. III.; its general direction (beginning at its lowest end, as we shall always do in these descriptions) is about N.W.; it is $7\frac{1}{2}$ miles in length to Aberdare, besides an extension thence, in nearly the same direction, by a *rail-way* for 8½ miles further; it is situate in the county of Glamorgan in South Wales, and is not far from the sea-coast, or very greatly elevated above the same. The great coal and iron-mines, and works near Aberdare, Furno-Vaughan, &c. seem its principal objects. It begins in the *Glamorganshire* canal near Eglwysila, and terminates in the *Neath* canal at Abernant. The first $4\frac{1}{2}$ miles of the canal are level, and thence it rises 40 feet to Aberdare. Mr. *Thomas Dadford*, jun. is the engineer. A lock of sufficient height, with proper side-weirs, was made near the lower end, to prevent the *Glamorganshire* canal from suffering by floods, that may make their way into and through this canal. The company may raise 33,500l. shares, 100l. each. The rates of tonnage are too long for such an abridged account as this; they will be found in *Phillip's 4to. History of Inland Navigation*, Appendix, p. 38. Boats 12 feet long and 5 feet wide may be used, free of toll on the pounds, by the adjoining occupiers, for their husbandry purposes. At Aberdare works are some curious machines; one is said to be a pair of water-wheels, working one below the other like a figure of 8.

ABERDEENSHIRE CANAL. Acts 36 and 41 of Geo. III.—The general direction is about N.W. for 19 miles in length, in Aberdeen county in Scotland; it is near the sea-coast, and is not greatly elevated in any part; the principal objects seem the supply of the town Aberdeen, the exportation of granite stone from the famous quarries on its banks, and to form a communication between the harbour of Aberdeen and the vales of the river Don. It begins in the tide-way in the *Dee* river in Aberdeen harbour, and follows the course nearly of the Don river, in which it terminates at Inverury bridge; and passes the villages of Old Machar, Newhills, Dyce, Kinnellar and Kintore.

rose. The rise is 170 feet by 17 locks; the width of the canal is 20 feet, and depth of water $2\frac{1}{2}$ feet. The harbour of Aberdeen, (connecting with the *Dee* river near its mouth, at the S. E. end of this canal), was surveyed many years ago by Mr. *John Smeaton*, and lately by Mr. *Thomas Telford*, who has, in his reports to parliament, recommended making it capable of receiving ships of 18 or 20 feet draught of water. It appears that this canal was completed and opened in June 1805. The company might by the first act raise 30,000*l.*, shares 50*l.* each; and by the 2d act 20,000*l.* more might be raised on 20*l.* shares, bearing 5 per cent. interest. Half-mile stones to be erected. Pleasure-boats of twelve feet long, and four broad may be used on the pounds.

ADUR RIVER. The general direction of this river is nearly north for 12 miles in the county of *Sussex*: its objects are the import of coals, deals, &c., and the export of farming produce. New Shoreham and Steyning are considerable towns on or near it. It commences in the sea at Southwick below Shoreham harbour, and terminates at Bines-bridge in West-Grinstead. In September 1805, notices were given of the application for an act for extending this navigation from Binesbridge to Baybridge in Shipley.

Alford and Wainfleet. In July last (1805) a survey was ordered for an intended canal from Wainfleet haven to the town of Alford, the general direction of which line is nearly north, and about 12 or 13 miles in length, in the county of *Lincoln*: this line is near the coast, and seems but very little elevated above the sea: its principal objects seem the supply of Alford, and the export of husbandry produce: it is proposed to pass the town of Burgh. Wainfleet haven is said to be a very good harbour for trading ships.

ANCHOLME NAVIGATION. Act 42 of Geo. III.—The general direction of this navigation is nearly south: it is almost straight (except the last four miles), and about 26 miles in length, in *Lincolnshire*. It is situate within 15 or 20 miles of the coast, and runs nearly parallel thereto through fens and level grounds for great part of its length. Its objects, besides a better drainage of these fens by a wide and straight cut, instead of the old course of the river Ancholme, seems the supply of Market-Raifin and of Caistor (by means of the *Caistor* canal, which joins it at South Kelsey), and the export of husbandry produce. It begins in the tide-way in the *Humber* river near Winttingham, and extends to the town of Market-Raifin, passing near the town of Brigg.

ANDOVER CANAL. Act about the 30th of Geo. III. Its general direction is nearly north, and pretty straight, following the course nearly of the *Anton* river (which is navigable to Rumsey) for $22\frac{1}{2}$ miles in length, in *Hampshire*; it is near the coast, and not very greatly elevated in any part above the level of the sea. Its general objects seem to supply fuel to the country, and to export its surplus of farming produce. It connects with the *Southampton* and *Salisbury* canal, the latter entering it at Red-bridge, and leaving it again at Kimbridge mill. The town of Southampton, near its south end, is the 68th in the order of British population, having 7,913 inhabitants. This canal begins in the tide-way in *Southampton-water* at Redbridge, and terminates at Barlow's mill near the town of Andover; the towns of Rumsey and Stockbridge being on its course. Its rise is equal to 176*ft.* and it is fed at its upper end from Pilhill brook. This line was surveyed by Mr. *James Brindley* in the year 1770, and an act proposed, but the opposition of the land-owners prevented one being ob-

tained, until it had been again surveyed in 1780, by Mr. *Robert Whitworth*; in a few years after which it was completed for use.

Arklow and Ovoca. In 1792, Mr. *William Chapman* surveyed the vales of the Ovoca river in Ireland, and recommended to render the improvement of Arklow harbour, which was then intended, more beneficial to the adjacent country, by connecting therewith a system of small canals up the rapidly ascending vales of the Ovoca, by rising 70 or 80 feet at once in proper places, by some of the substitutes for locks, of which we have before spoken.

ARUN RIVER. This navigation has nearly a north direction for 15 or 16 miles in the county of *Sussex*. To supply coals, and export farm produce, seem its principal objects; which are facilitated by the *Arundel* canal, that joins it near Stopham bridge, and would be further accomplished, were the *Surry iron rail-way* extended to it at Wisborough-green bridge, as was proposed in the year 1801. It proceeds from the sea at Arundel haven to Wisborough-green bridge, passing the town of Arundel in its course.

ARUNDEL CANAL. Act 31 of Geo. III.—The general direction is west for about 11 miles, following the course of the river Rother, in the county of *Sussex*. It is about 12 or 13 miles from, and nearly parallel to, the sea-coast, above which it is but little elevated. The supplying of the inhabitants with coals, and exporting of husbandry produce, seem the principal objects of this canal. It commences in the *Arun* river near Stopham bridge, and terminates at the lower flat near Midhurst, with a side cut of about one mile in length to Haslingbourn bridge in Petworth parish. The line being through the parishes of Stopham, Coldwaltham, Bury, Fittleworth, Ergdean, Coates, Sutton, Petworth, Duncton, Burton, Tillington, Lodsworth, Selham, Ambersham, Easebourn, Woolavington, and Midhurst. This canal is the property of that public spirited nobleman the earl of Egremont, but open to the use of the public, on paying certain specified tolls.

ASHBY DE LA ZOUCH CANAL. Act 34, Geo. III.—The general direction of this canal, though in a serpentine course, is nearly north, 40 miles in the counties of *Warwick*, *Leicester*, and *Derby*. It commences near and almost upon the grand-ridge on its eastern side, and near its other extremity is tunnelled through a yet higher side-branch of the great ridge. The conveying away of the coals and lime-stone from this last ridge, and the supply of the towns on its borders by means of the *Coventry* canal, with which it connects, are its principal objects. *Coventry*, which is near it, is the 24th town for population in Britain, having 16,034 inhabitants; while *Hinckley*, which is upon the line, has 5,070 persons, and is the 120th in order. *Market Bosworth* and *Ashby-de-la-Zouch* are other considerable towns near or on the line; the commencement of which is at Marston bridge near Nuneaton, on the *Coventry* canal, and the termination is by a *rail-way* (of $3\frac{1}{4}$ miles) at Ticknall lime-works; there also is a *rail-way* branch of 6*½* miles to Cloudhill lime-work; another to Mr. *Wilke's* Measham collieries of 5 miles: a cut of $2\frac{1}{4}$ miles to Swadlingcote coal-works; another of $\frac{1}{4}$ mile to Staunton lime-works; another is to be made to Stanton-Harold park (if desired by the earl of Ferrers, the proprietor thereof); and there is another short cut of 200 yards to Hinckley wharf. The first 30*½* miles of this canal are level, extending to Oakthorpe engine on *Ashby* woulds, and forming with parts of the *Coventry* and *Oxford* canals, a level of 73 miles in length, being, without the branches, the longest in the United Kingdoms, and rendered more singular by being on so high a level, as to cross the grand ridge with-

out a tunnel. From Oakthorpe engine to the Boothorpe feeder, $1\frac{1}{2}$ mile, is a rise of 140 feet, thence the summit level of $4\frac{1}{2}$ miles extends, through the principal tunnel to its north end; thence to the Cloudhill branch, $\frac{1}{2}$ of a mile, is a fall of 84 feet, and thence to Ticknal works is it level. The Cloudhill, Swadlingcote, and Hinckley branches, are level with the line, and the Staunton branch falls 28 feet therefrom. On this canal are two tunnels, one near Ashby-de-la-Zouch town of 700 yards in length, and the other near Snareton of 200 yards. At Shackerton and at Snareton there are aqueducts; and at Boothorpe a reservoir with a steam-engine for pumping up its water into a feeder for the summit-level of the canal. The rail-way branches, and some part of the canal were completed previously to May 1802, but it was not until about May 1805, that the whole of the line was completed and opened. The company were authorised to raise 200,000*l.*, the amount of shares 100*l.* each. Public wharfs are provided on Ashby woulds, and at Green-hills near Sutton Cheney. Sir George Beaumont, the owner of collieries at Coal-Orton, to which rail-ways had previously been made at great expence connecting with the *Leicester* navigation, is to be compensated, and the company may purchase certain annual quantities of his coals for such purpose. This company is also bound to indemnify the *Leicester* navigation, and to allow them a rate of 2*s.* 6*d.* per ton on all coals carried upon this canal or its branches beyond a certain point from the coal-pits in the neighbourhood of their water-levels or rail-ways. To the *Coventry* canal company they are also bound to pay 5*d.* per ton for all coals, and some few other articles, which pass upon any part of this canal or its branches, and afterwards upon any parts of the *Coventry*, the *Oxford*, or *Grand Junction* canals, or from either of those canals to this: and for duly enforcing this last compensation, the *Coventry* company are authorised to erect toll-house and bars, and station their own collectors when and where they may chuse upon the works belonging to this company. The rates of tonnage allowed, vary from 2*d.* to $\frac{1}{2}$ *d.* per ton per mile on different goods, while some articles are to be allowed to pass toll free. Our limits will not allow of stating these particulars, which will be found in *Phillips's History of Inland Navigation*, 4to. Appendix, p. 128. In June 1796, a survey was made by Mr. *Whitworth* for connecting the north end of this canal, by means of the proposed *Commercial* canal, with the *Trent and Mersey* and the *Chester* canals, and opening the long wished for communication between London, Hull, Chester, Liverpool, Manchester, &c. for river-boats of 40 tons burthen. In consequence of the failure of this scheme, in the January following, it was proposed to extend this canal to the *Trent* at Burton, and to the *Trent and Mersey* at Shobnall.

AVON RIVER, (Bath.) The general direction of this navigation is about S. E., in length 26 or 27 miles, by a crooked course in the county of Somerset, and skirting that of Gloucester: it opens into the *Severn* river, and is most of it a tide-way. The objects of this navigation are as various, as the imports and exports of such large places as Bath and Bristol, and a populous neighbourhood require; besides its connection with the *Kennet and Avon* canal, and the other canals therewith connected. The city of Bristol is the 7th place in the order of British population, having 68,645 inhabitants, and Bath is the 12th, with 32,200 inhabitants. The commencement of this river is in the King's road in the *Severn* river (here about seven miles wide), and its navigation ends at Bath, near the commencement of the *Kennet and Avon* canal. About the year 1803, or 1804, an act was obtained by the *Bristol Dock* com-

pany, for converting about 70 acres of the old and crooked course of the *Avon* into a vast floating-dock for ships, and to cut a new channel for the river. About May 1804, these works commenced, under Mr. *W. Jessop*, and great progress has been made towards their completion. Two cast-iron bridges are erecting over the *Avon* near these works; one of them from Clifton-down to Leigh-down will, it is said, be 200 feet high above the surface of the water, and the other sufficiently high for ships to pass under it. That essential appendage, a towing-path, was wanting on this river, until the above company was established, who are making one on each side of the river, from Pill up to Bristol, and one thence to Hanham mills; from which place up to Bath, a towing-path is proposed to be extended, under an act, for which notices have just been given; this last part of the river is also intended to be improved in other respects. We have, also, lately seen a notice for a further application to parliament by the *Bristol Dock* company, for erecting a dam and overfall, with sluices, &c. at Red-cliff in Bedminster, to keep up the water for the new floating docks, and for other amendments of their former acts; in 1796 it was proposed that the *Kennet and Avon* canal should be extended to this river at Bristol. At Bitton below Bath, it was lately proposed, that the *Gloucestershire* rail-way should connect. In 1762, Mr. *Stratford* gave a design for a new stone bridge in Bristol of one arch, 150 feet span, and 32 $\frac{1}{2}$ feet high, which Mr. *John Smeaton* examined and approved; and in 1765, the last mentioned engineer gave a design and estimate for a floating dock nearly as above; after which, Mr. *Campion* made other designs.

AVON RIVER, (Salisbury.) The direction of this navigable river is very nearly north, and its length near 30 miles, in the counties of Hants and Wilts. The general objects of this navigation are the supply of Salisbury, and the adjacent country, and the export of its agriculture products. Near Salisbury, it connects with the *Southampton and Salisbury* canal. Salisbury contains 7,668 inhabitants, and is the 70th place in the order of our population; Fording-bridge, Ringwood, and Christ-Church, are likewise considerable towns on the line. The commencement is at the sea in Christ-Church harbour, and termination at Salisbury. The locks and works of this navigation had not been long completed, before a sudden flood happened, which swept away the greater part of them; in which state it lay until 1771, when Mr. *James Brindley* surveyed its course, and recommended a new canal by the side of the river; this was not however adopted, but the river-works have since been repaired; and the imperfection of them, was, we believe, among the most powerful motives for the adoption, in 1795, of the *Southampton and Salisbury* canal above mentioned. Mr. *Smeaton* examined Christchurch harbour in 1764, and recommended another pier to be built west of the old one.

AVON RIVER, (Stratford.) The general direction of this navigation is about N. E. by a crooked course of near 40 miles in Worcestershire and Warwickshire: the lower end thereof is but a few feet higher than the tide-way. The trade thereon is very various, depending in a great measure on the connection which it forms between the *Severn* river and the *Stratford* canal. Tewksbury, Pershore, Evesham, and Stratford, are considerable towns upon it. It commences in the river *Severn* at Tewksbury, and terminates at Stratford on Avon, near the junction of the *Stratford* canal. *George Perrot*, esq. is the proprietor of this navigation, and entitled to certain tolls, which were not to be lessened by the new communication with the *Severn*, which the *Worcester and Birmingham* and *Stratford* canals were to open, but

they were, by the act for the latter concern (33 Geo. III.), to make good any falling off in these tolls. About 1792, the *Stratford and Croxley* was proposed to proceed from this river at Stratford to the *Oxford* canal.

AXE RIVER. The general direction of this navigation is almost S. E. for about 11 miles in length by a crooked course in the county of Somerset: it is but little elevated. Its chief objects are the import of coals, and export of farm produce, Axbridge being the only town of any importance upon it. It commences in the Bristol channel near Uphill, and terminates near Axbridge. An act of the 42d Geo. III. passed, for altering and improving that part of it which is between Bleydon and Axbridge. At Bristol the *Bristol and Taunton* canal was once proposed to join this navigation; as the *Exeter and Uphill* also was designed to do at Uphill.

Axmouth and Langport. In 1769, Mr. James Brindley surveyed this line, which is nearly north, and about 30 miles in length, in Devonshire, Dorsetshire, and Somersetshire, crossing the south-western branch of the grand ridge. The objects of it seem to have been the supply of coals, exporting the products of the country, and opening a communication between the south coast and the Bristol channel, by means of the *Parret* river. Axminster, Chard, and Ilminster are the principal towns which this line was to approach; commencing in the tide-way at Axmouth, and terminating in the *Parret* river at Langport.

AYRE AND CALDER NAVIGATION. Act 9 or 10 of Will. III. The general direction of the *Ayre* river is nearly west, for about 40 miles by a serpentine course, from which the lowest part of the *Calder* river branches, nearly south-west, by a crooked course of about 15 miles, all in the West Riding of Yorkshire. The first of these rivers, though an internal one, begins near the level of the tide-way, and no parts of either of the navigations thereon are much elevated. The objects of this navigation were at first very considerable, in the imports and exports of the populous, manufacturing, and coal country through which it passes, and they are greatly increased, since it has formed part of the grand communications between the port of Hull, or the German Ocean, and the towns of Manchester and Liverpool, or the Irish Sea, by means of the *Leeds and Liverpool*, *Rochdale*, and *Huddersfield* canals, and others joining them. It connects near Snaith with a branch of the *Don* or *Dun* river; at Leeds, with some considerable rail ways extending to collieries from the coal-staith; near Wakefield it connects with the *Barnsley* canal. Leeds is the 8th place in point of population in Britain, having 53,162 persons, and Wakefield the 64th, with 8131 persons; Hunslet, near it, is the 104th, with 5769 persons; Snaith, Selby, and Pontefract, are also considerable places near this navigation, which begins in the *Ouse* river near Armin (to which place 50 and 60 ton sloops come up), and terminates its north-western branch at Leeds in the *Leeds and Liverpool* canal, and its south-western branch at Wakefield in the *Calder and Hebble* navigation. It has also a branch of canal about 4½ miles to the *Ouse* river at Selby, for shortening the distance to York, &c.; and another of 1½ mile near Mathley, between the *Ayre* and *Calder* rivers, for shortening the voyage between Leeds and Wakefield. The boats generally used hereon are 56 feet long, 13½ wide, and draw 3 feet water, with 28 tons of lading: these boats often go down the *Humber*, and round the coast, to the *Welland* and *Great Ouse* rivers. The proprietors are authorized to exact so high a rate of tonnage as 16s. per ton in winter, and 10s. in summer, between Leeds and the *Ouse*. It is provided in the *Huddersfield* act, 34 Geo. III., that if any communication is hereafter made with that canal to the eastward, the proprietors of this are to be compensated. The opposition of these parties proved

fatal, in 1769, to a canal which Mr. Brindley surveyed between *Selly* and *Leeds*.

BARNSELY CANAL. Act 33 of Geo. III. The first part of the course of this canal is south, and the remainder west, about 15 miles in length, in the West Riding of Yorkshire: its western end is considerably elevated above the level of the sea. The principal objects of it seem to be the export of coals and paving-stones, and forming a short communication with Rotherham and Sheffield (by the *Dearne and Dove* canal, with which it connects at Eyming wood near Barnsley), and Leeds, Wakefield, Halifax, Manchester, Liverpool, &c. Wakefield is the 64th town in the order of population, with 8131 persons; Barnsley is also a considerable town. This canal commences in the lower part of the *Calder* river, or *Ayre and Calder* navigation, a little below Wakefield town, makes a turn when it arrives at the *Dearne* river, and terminates at Barnby-bridge near Cawthorn; there is a branch of 2½ miles to Haigh-bridge in Wooley parish, and rail-way branches to Barnsley town 1 mile, and to Silksstone 1½ mile. From the *Calder* to the junction of the *Dearne and Dove* canal, about 9 miles, is a rise of 120½ feet: this is effected by three locks together, near Agbridge, having a low level or side-cut brought up to near the upper pound, with a steam-engine for pumping up the water again, which is let down by the lockage; by 13 other locks near Watton, and a long side-cut, from which engines pump up the water to supply the pound above these; and, near Bargh-bridge, by 4 other locks, a side-cut, and engine. On the Haigh-bridge branch there are also 7 locks together, with a low side-cut, and a steam-engine for pumping up the water required for lockage. At Eym is an aqueduct-bridge. This canal is adapted to the use of the same sized boats as navigate the *Calder*. It is provided, that any rail-ways or stone-roads, that may be made northward from Bargh-bridge (or mill) shall be discontinued or removed, if a cut shall be made from the *Calder and Hebble* navigation, to connect herewith; also, that the steam-engine near Warmfield shall be so constructed as to burn its own smoke, to prevent any nuisance to the inhabitants. The company were authorized to raise 97,000l., shares, 100l. each. This canal was completed and opened 8th of June 1799. The rates of tonnage on different articles are various: some fixed at 6d. to 4d. for the whole length of the canal; and various others at 3d. to ½d. per ton per mile, with several exemptions, rates of wharfage, &c. See *Phillips's History*, 4to. App. p. 40 to 43. The engineers were Mr. William Jessop, Mr. William Bright, and Mr. Goll.

BARROW RIVER (Ireland). This is one of the rivers, for the improvement of whose navigation the Irish parliament granted several sums of the public money, between the years 1753 and 1771, amounting to 13,600l. It is probable that less than the half of this amount, raised and expended by individual proprietors, with that circumspection which self-interest can alone inspire, would have effected what, we are told, this expenditure has left very imperfect. At Portarlington and at Monasteraven this river was to be joined by different branches of the *Grand Canal*.

BASINGSTOKE CANAL. This line of canal was first proposed in 1772, as an extension of, or appendage to, the canal intended for shortening the course of the navigation of the river *Thames*, between *Reading* and *Maidenhead*; but it was some years before the first act for this was obtained, in 1778; the other act is the 35 of Geo. III. The general direction of this canal is nearly west, by rather a crooked course of 37 miles in length, in the counties of Surry and Hants; the summit-pound thereof of 22 miles in length is upon a high level, near the south-east branch of the grand-ridge on its north side. The principal objects thereof seem the import

of coals, and export of timber and agricultural produce, from and to the *Thames*. Basingstoke and Odiham are considerable towns on or near its line, which commences in the *Wey* river at Westley, (about two miles from its junction with the *Thames*;) and terminates at Basingstoke. A cut of 6 miles in length, and level with the summit-pound, was proposed northward to Turgis Green, but has not yet been begun, as we understand. The first 15 miles from the *Wey* river has a rise of 195 feet by 29 locks to Dadbrook, (the part at each lock being about 7 feet) from whence to Basingstoke it is level: 45 ton boats are used on this canal. At Grewel is a tunnel, part of which intersects the chalk strata, (about $\frac{1}{2}$ mile in length) that had the misfortune of falling in; but the same has, we are told, been substantially repaired. At Alderhot there is a large reservoir for the supply of this canal, (which was begun in 1788 and completed in 1796, at the expense to the proprietors of 160,000*l*.) and a feeder from the river Loddon. There are 72 bridges over the canal, and several culverts across, to convey the water from the upper to the lower lands. The company were authorized to raise 186,000*l*. The prices of freight from Basingstoke to Hamboroughwharf, London, for coarse and heavy goods, was, in 1800, 15*s*. per ton; to the dockyards, as far as Deptford, 16*s*.; and to Blackwall docks, 17*s*. per ton for timber, &c. The length of a passage is three or four days. In the year 1796 there was an intention of extending a branch from near Grewel tunnel, of about 22 miles in length, to the navigation that connects with *Southampton water*; about 1794 there was an expectation of its being joined by the canal which will next be mentioned; and in 1801, notices were given of an intended cut from Chilton-moor to Bagshot-green in Windlesham; for want of these or some other junctions that shall throw a greater trade into it, this canal has, though improving, been as yet rather unproductive to the share-holders. In 1800 there was a proposal for extending the *Grand Surry* to meet this canal at the *Wey* river.

Basingstoke and Hampstead. About the year 1794, a line of canal was projected, and notices given, extending from the *Basingstoke* canal at that town, to the *Kennet and Avon* canal at Hampstead, 3 miles above Newbury, the length of the line was said to be 22 miles; we have since heard nothing of this scheme.

BELFAST TO LOCH NEAGH. This line of canal was begun under an act of the Irish parliament several years ago, for forming a communication with the sea at Carrick-fergus Bay and the above inland lake or loch, as also for exporting marble from the quarries thereof near its line.

Belper Canal. In September 1801, notices were given for a proposed canal, rail-ways, &c. from the *Cromford* canal at Bull-bridge, to Black-brook-bridge, through the parishes of Crick, Heage, Ashley, Hay, Belper, and Duffield; all in Derbyshire.

Biggleswade and Hertford. Several years ago a proposal was made, for joining the *Ful* river at Biggleswade with the *Lee* river at Hertford, by means of a canal passing the town of Hitchin, by which an internal communication between Lynn and London would be opened; but the difficulty of supplying a summit-level near Stevenage with water, seems a greater obstacle than the expected trade would pay for surmounting.

BIRMINGHAM (old) CANAL. Acts the 8th, 9th, 11th, 23d, 24th, and 34th of Geo. III. the last but one of which acts, unites the concerns of this company with those of the *Birmingham and Fazeley* canal below; but as these canals were constructed and remain under distinct provisions in the acts, and take different directions from the town of Birmingham, where they meet, we have deviated from our usual rule and continued them separate in our account. The

general direction of this canal is about S. E. and 22 $\frac{1}{2}$ miles in length by a crooked course, through the counties of Stafford, a detached part of Salop and Warwick: it skirts along near the grand-ridge on its eastern side, at so high a level as to cross it near its northern end without any deep cutting or tunnel; and, in that high situation is wholly supplied by reservoirs for flood waters, or steam engines which pump up the water again, after it has been let down for lockage, or out of old and disused coal-pits. The principal objects of this canal are the carrying away of the coals from the numerous mines on its banks and branches, and the manufactured goods of Birmingham to Liverpool, Manchester, &c. It connects near Farmer's-bridge at Birmingham, with the *Worcester and Birmingham*, at Tipton Green with the *Dudley* canal, and near Wolverhampton with the *Wyrley and Edington* canal. The great towns on and near the same are, Birmingham, the 6th in the order of population, containing 73,670 inhabitants: Wolverhampton, the 33d, with 12,565 persons; Walsal, the 47th, with 10,399 persons; Dudley, the 49th, with 10,107 persons; and Bilston, the 87th, with 6,914 persons: in the centre of so large and active a population as this, the wonder in a great measure ceases, that this canal, constructed and carried on under such peculiar disadvantages, should nevertheless have proved the most lucrative concern of the kind in the kingdom. This canal commences in the *Staffordshire and Worcester* canal at Alderley or Autherly, near Wolverhampton, and terminates in the *Birmingham and Fazeley* canal, at Farmer's-bridge, near the upper end of the town of Birmingham, the line being double in two places, viz. at Tipton, where a tunnel of near 1000 yards, and a canal of 1 $\frac{1}{2}$ mile in length, between Bloomfield and Deepfield has been made since 1794, for avoiding a zig-zag loop round Tipton hill, of 4 miles; also at the Smithwick locks, where two canals with 3 locks on each have been made, since 1787, for accommodating the immense traffic which is hourly passing. The collateral cuts are very numerous, the principal one extends from near Bromwich to the town of Walsal, by a crooked course of 8 $\frac{1}{2}$ miles; from this branch nine or more branches strike off to as many coal-works, &c. on each side of it; the termination of some of these are, near Wednesbury town, at Broad-water engine, Toll-end, Bradley, Bilston, David's Ram-farm, and other coal-works: the lengths of all which are several miles. From the line there is also a cut of about one mile, to Oker-hill coal works; another to Messrs. *Dolton and Watt's* famous Solio foundery, and another to Newhall-ring basin and wharf in Birmingham. In the first mile and three quarters, the rise from the *Stafford and Worcester* canal is 151 feet, by means of 25 locks, then 18 $\frac{1}{2}$ miles are level; a descent of 18 feet then takes place, by 3 locks (on each of the two branches before-mentioned); the remainder of the line about 4 $\frac{1}{2}$ miles is level, to the junctions of the *Birmingham and Fazeley* and the *Worcester and Birmingham* canals at Farmer's bridge. The Walsal branch, where it leaves the line, has a fall of 18 feet by means of 3 locks, and about two miles further near Rider's-green, a further fall of 48 feet by 6 locks, whence to Walsal is level; the Toll-end branch has a rise of 15 feet by 3 locks, and the Bradley of 20 feet by 4 locks, all the other cuts being level. This canal was originally cut 28 feet wide at top, 16 at bottom, and 4 $\frac{1}{2}$ deep; but by constant wear and widening it is now 40 feet wide at the top on the average. The locks are 70 feet long and 7 wide in the clear, and the boats carry about 22 tons. At the coal-wharf near Farmer's-bridge, and at its side cuts, 40 boats can unload at the same time; the Newhall-basin of 2 acres, is for the unloading and loading of timber, stone, slates, and general merchandize, no wharfrage is charged at either of these wharfs. Originally, there

was a summit-level on the line of about one mile in length at Smithwick, 18 feet higher than at present, (of which 1000 yards was deep-cutting, 28 feet in the deepest part) and it was supplied until 1787, by a steam-engine at each end; when, owing to the increasing trade, this summit was cut down, and 6 locks removed, making the deep-cutting one mile in length, and 46 feet deep in one place; and though this work was $2\frac{1}{2}$ years in hand, and cost 30,000*l.* yet it was so managed, that the passage of boats was only 14 days interrupted thereby. There is a considerable reservoir near Oldbury, and another near Smithwick, with feeders for conveying their waters into the summit level. The celebrated Mr. James Brindley was the original engineer, and on the 6th of November 1769, he completed 10 miles of the line and branches next Birmingham, by which coals were first brought by water to that great town from near Wednesbury, and their price to the inhabitants was lowered at once from 15*s.* and 18*s.* to 7*s.* 6*d.* per ton! In October 1772, the line was opened, and in June 1799, the Walfal branch was completed. The proprietors were authorized to raise 115,000*l.* before the consolidation of this and the *Birmingham and Fazeley* concerns. At first the shares of this were 100*l.* each; but were by the second act 9th Geo. III. reduced in number and made 110*l.* shares; those created since the 24th Geo. III. are 170*l.* shares. The original tonnage on all goods, (excepting lime stone) was $1\frac{1}{2}$ *s.* per ton per mile, and for lime-stone and lime, $\frac{1}{2}$ *d.* per ton, except for manuring of the lands of the adjoining proprietors, and road materials were allowed to pass toll-free; but the subsequent alterations in the several acts since would much exceed our limits to mention, those who are desirous of further information will find it in Mr. John Cary's *Inland Navigation*, 4to. pages 36 to 45. By the *Dudley* act, 25th Geo. III. this company are entitled to certain tolls on goods passing on or off of that canal to this; and, by the *Wyrley and Essington* act (32 Geo. III.) to other rates for the junction therewith; all which may be seen as above. About the year 1790, a cut was proposed from this canal (instead of the *Dudley* junction) to Netherton collieries $12\frac{1}{2}$ miles, by a tunnel through the grand-ridge near Oldbury, of 2,078 yards, and 184 feet under the hill: in 1796, a foundery and large works belonging to Messrs. Bolton and Watt, were erected on the banks of this canal 5 miles from Soho. This canal extending across a country full of coal, it was apprehended that the sinking of the old pits might damage the same, and the company have power to enter and examine mines to prevent their working within 12 yards of the canal, except by passages of 4 feet wide, and 6 feet high: for want of more strict attention to this, some of the branches near Wednesbury have been undermined and broke in, so as to cause the canal to be abandoned in that part. From some of the old worn out coal-mine shafts near Billstone, a lambent blue flame arises in the night, of which a great deal has been said and written. Proprietors of mines within 1000 yards of this canal, or its branches, may make rail ways thereto.

BIRMINGHAM AND FAZELEY CANAL. Acts 23d, 24th, 25th and 34th of Geo. III.; the second of these acts is for consolidating this concern with the old *Birmingham* above; but each part of the canal remains subject to its own original regulations, as above observed, and the last but one is for consolidating $5\frac{1}{2}$ miles of the *Coventry* canal herewith, subject to the original powers of the *Coventry* act (8th Geo. III.) under which it was set out and made. The general direction of this canal is S. W. exclusive of the late *Coventry* part, which lies in a direction between N. and N.W. from the original termination at Fazeley: the length of the whole is 20 $\frac{1}{2}$ miles in the counties of Stafford and Warwick: the whole of this line of canal is considerably elevated, but

particularly the S.W. end in the town of Birmingham, which is situate near the grand-ridge on its eastern side. The great objects of this canal are, the export of the manufactures of Birmingham towards London or Hull, and of coals; the supply of grain and other articles to Birmingham and its populous and busy neighbourhood; it connects with the *Wyrley and Essington* canal near its commencement at Whittington-brook, with the *Coventry* at Fazeley, with the *Warwick and Birmingham* at Digbeth, and with the *Worcester and Birmingham* canal near its termination at Farmer's-bridge. Birmingham, as before observed, is the 6th British town, with 73,670 inhabitants, and Tamworth near the line, is a considerable place. The commencement of this canal is in the detached part of the *Coventry* canal, at Whittington-brook, and its termination in the old *Birmingham* canal at Farmer's-bridge at the top of Birmingham town. From the N.E. entrance of the town of Birmingham, a branch skirts the town to the lower part of it called Digbeth, and there connects with the *Warwick and Birmingham* canal. From the detached part of *Coventry* canal at Whittington-brook, to its junction with the line of that canal at Fazeley, and thence past the small aqueduct bridges near Middleton-hall, about $8\frac{1}{4}$ miles are level with the *Coventry* canal; from thence to the aqueduct bridge over the Tame river at Salford, $9\frac{1}{2}$ miles, has a rise of 50 feet by 14 locks, thence to the Digbeth branch, near $1\frac{1}{2}$ mile, has a rise of about 71 feet by 11 locks; thence to the old *Birmingham* canal at Farmer's-bridge, about $1\frac{1}{2}$ mile, is a rise of about 85 feet by 13 locks; the Digbeth cut, of about $1\frac{1}{2}$ mile in length, has a fall of 40 feet, by 6 locks to the *Warwick and Birmingham* canal. The width of this canal is about 30 feet, and its depth $4\frac{1}{2}$ feet. The locks are 70 feet long and 7 wide in the clear, carrying boats with about 22 tons of lading. There are a wharf and basin at Digbeth for the accommodation of the lower part of Birmingham. The Salford aqueduct bridge has 7 arches over the Tame river of 18 feet span each. The Digbeth cut is tunnelled or rather arched over in the town of Birmingham; there is also a short tunnel on the line where the Liverpool road crosses. The *Coventry* company being unable for want of money to proceed with the essential part of their line, between Fazeley and Fradley, where it joins the *Trent and Mersey* canal, the latter company for the sum of 500*l.* over and above the actual expences, undertook to complete this length, by agreements of the 29th October 1783; which the act (of 23d of Geo. III. above) confirmed; this they accomplished, the half nearest to Fradley in January 1787, which the *Coventry* company in Oct. 1787 purchased of them, agreeable to the 23d Geo. III. (which occasions them now to have a detached length of canal); the other half, between Whittington-brook and Fazeley, was completed in October 1789, and on payment of the cost thereof by this company, it was conveyed and made over to them, agreeable to the act above quoted. On the 12th of July, 1790, the aqueduct bridge at Salford being completed, as well as the line of canal, the same was opened, and the water communication between Birmingham and Hull or London, was thereby effected. The sums of money to be raised for this canal, were not distinguished in the acts from what was intended for the extension and improvement of the old *Birmingham* canal, the amount of each share was 170*l.*; but the act 24th Geo. III. limiting the number of shares to 500, they seem now to be variable. The rates of tonnage are too complicate for us to attempt their particulars, and we must refer the readers to J. Cary's *Inland Navigation*, pages 40 to 44, and pages 75 and 77. By the *Warwick and Birmingham* act (33d Geo. III.) certain duties are secured to this on goods passing from or to that canal, which may be seen in Cary, page 44. It is provided

that the tonnage per mile on coals, is to be the same on this and the *Coventry and Oxford* canals.

Bishopstortford and Cambridge. In the year 1785 Mr. *John Phillips*, in a quarto treatise, recommended a line of canal from the *Stort* river, at Bishopstortford, to the *Cam*, at Cambridge, either by way of Littlebury and the Granta river, or near to Royston by the upper part of the *Cam*; which might be done, he says, for little more than 20,000*l.* but no levels, or other essential particulars are given; nor do we hear of any such, when Mr. *R. Dodd* again revived this idea in 1803, and wished to make this line part of his *North London* canal.

Bishopstortford to Wilton. In 1789 Mr. *John Rennie* was employed by several gentlemen of Essex to survey and report on a line of canal from Hifs, near Wilton, on the Brandon or Little *Ouse* river, at the edge of the fens in Suffolk, to the *Stort* river at Bishopstortford; the distance from the little *Ouse* to Ugley, the beginning of a proposed tunnel (of $\frac{1}{4}$ of a mile) near Effingham, $45\frac{1}{2}$ miles, with a rise of $251\frac{1}{2}$ feet; thence to Fuller's end, near Effingham, $2\frac{3}{4}$ miles, and level; and thence to the *Stort* at Bishopstortford, $4\frac{1}{2}$ miles with 50 feet fall; a cut was proposed to Burwell on a branch of the *Cam* river, and it was to cross the *Lark* river. Several large reservoirs were designed, and three tunnels, two of them being necessary to reach the town of Saffron-Walden, and to miss Audley park. The estimate was 175,000*l.* and a bill was brought into parliament, in 1790, for the same, but it there met a fatal opposition.

BLACKWATER NAVIGATION (Ireland). This river falls into Loch Neagh, and for extending a navigation therefrom to the Dungannon and Tyrone collieries, the Irish parliament, between 1753 and 1770, granted various sums of the public money, amounting to 11,000*l.*; a canal with 8 locks, terminating in a basin, was constructed before Mr. *Davis Duckart* the engineer was employed thereon; who, finding the three miles with 200 feet rise, which remained to do to reach the Tyrone collieries, to be too great for a canal with locks, he constructed, about 1776, four water-levels, with three inclined-planes, of 70, 60, and 50 feet rise, to connect them, on which small boats were made to ascend and descend, as we have already mentioned, these being the first inclined-planes for boats brought into use in the United Kingdom; it appears, however, that these were soon laid aside in this place, and a rail way was substituted. This navigation was intended to connect with the *Newry* canal.

BLYTH RIVER. This river, between Northumberland and a detached part of the county of Durham, appears to be navigable but a small distance above Blyth harbour; but we understand it has several considerable rail-ways connecting with it, for bringing down the produce of the collieries to the shipping.

BOYNE RIVER (Ireland). This is one of the rivers on the east coast of Ireland, for which the parliament, between 1768 and 1771, granted 9,507*l.* for improving its navigation. At Edenderry it was proposed to be joined by a cut from the *Grand Canal*.

BRADFORD CANAL. Acts 11 and 42 Geo. III. The general direction of this short navigation is south nearly, and 3 miles in length, in the West Riding of Yorkshire. It is not considerably elevated: its objects are the export of coals, iron, and stone, the produce of the neighbourhood of Bradford, and the supply of Bradford town, which is the 95th in the series, with 6,393 inhabitants. It commences in the *Leeds and Liverpool* canal at Winhill, in Idle parish, and terminates at Bradford, where rail ways of considerable extent connect with it, one of them goes to the collieries and iron-works on Wibsey

Slack; and the descent is so steep that the waggons run down without horses, having their velocity regulated by a man who rides behind and uses the convoy or brake upon the wheels, as occasion requires. From the *Leeds and Liverpool* canal to Bradford is a rise of 81 feet by 8 locks; the width of the canal at top is 24 to 30 feet, and its depth is 5 feet; the locks are of the same width and length as those of the *Leeds and Liverpool* canal. The company were empowered to raise 6000*l.* in 1001. shares. Boats passing the whole or any part of the distance on this canal are to pay 6*d.* per ton for clay, bricks, stone, coals, lime, dung, and manure; and 9*d.* for every ton of iron, timber, and all other goods. This canal was finished in 1774. The last act was found necessary, in order to make good the title to some lands which had been long before purchased for the works.

BRECKNOCK AND ABERGAVENNY CANAL. Acts 7; and 44 of Geo. III. The general direction of this canal is about N.W. 33 miles in length, in the counties of Monmouth and Brecknock in South Wales; it begins a few miles from the coast, and soon after comes near and follows the course of the *Uske* river, no part of it being very greatly elevated. Its objects are the exportation of coals, iron, and other mineral products of the country round Abergavenny, by means of the *Monmouthshire* canal, and the supply of Pontypool, Abergavenny, Crickhowel, and Brecon towns, that are near its course. It commences in the *Monmouthshire* canal, 1 mile from Pontypool, and terminates at the town of Brecon; it has several rail-way branches: viz. to Abergavenny 1 mile; to Wain-Dew collieries and iron-works $4\frac{1}{2}$ miles (near $2\frac{1}{2}$ miles of this last being double on each side of the brook); and, to Llangroiney $1\frac{1}{2}$ mile. From the *Monmouthshire* canal, the first $14\frac{1}{2}$ miles are level, to 3 miles above the Abergavenny branch, thence to Brecon is $18\frac{1}{2}$ miles, with a rise of 68 feet. Near its commencement it crosses the little river *Avon*, on an aqueduct, and shortly after passes a tunnel of 220 yards in length. The engineer is Mr. *T. Dadford* jun. The Wain-Dew rail-ways, and the canal above them, up to Brecon, appeared to be finished in June 1802, and by this time we expect the whole is completed, or nearly so. The company were at first authorized to raise 150,000*l.* and a further sum by their second act, shares 100*l.* each. The rates of tonnage are to be the same as those on the *Monmouthshire* canal, which see in *J. Phillips's History*, 4to. App. p. 18. Horses, mules, and asses are to pay 1*d.* and cows, or neat cattle $\frac{1}{2}$ *d.* each at certain toll-gates on the rail-ways. The *Monmouthshire* canal, on account of the great benefit this will confer on it in tonnage, agreed to pay this company in March 1794, the sum of 3000*l.* In May last (1805) it was proposed to extend a rail-way branch from this canal to connect with the river *Wye*.

Bredon Rail-way. About the year 1793 it was in contemplation to make a rail-way and canal from the famous lime-works at Bredon to the *Trent* river, opposite to Weston Cliff; and in consequence, a clause is inserted in the *Derby* canal act, of 33 Geo. III. binding them to make a cut from the *Trent* at Weston Cliff to the *Trent and Mersey* canal, which runs parallel with the *Trent*, whenever this scheme shall be adopted, in order to give this lime a readier course into Derbyshire.

BRIDGEWATER'S CANAL. Acts 32 and 33 of Geo. II., the 2d, 6th, (*Trent and Mersey* act) and 35th of Geo. III. The general direction of the principal line of this canal is nearly N.E. (and not a great way from its eastern end, a main branch goes off in a N.W. direction nearly); the length is 40 miles, in the counties of Chester and Lancaster. It begins in the tide-way; above which the whole of it is elevated 82 feet at low-water, except about 600 yards, which the locks

occupy to gain this ascent. The great objects which induced the late excellent and patriotic *duke of Bridgewater* to undertake and to expend a princely fortune on the completion of this canal were, the supply of the town of Manchester with coals from his estates near Worsley; the cheaper and more expeditious conveyance of goods, between Manchester and Liverpool, than the *Mersey and Irwell* river navigation then furnished; and between both of these places and the interior and most remote parts of the country, by means of the *Trent and Mersey* (which it joins at Preston Brook,) and its connecting canals. Other and more direct communications have since been made between it and the interior and eastern parts of the kingdom, by means of the *Rochdale* canal and those connecting therewith. Manchester is the 2d place in Great Britain for population, having 84,020 inhabitants, Liverpool the 4th with 77,653 inhabitants, and Warrington the 45th with 10,567 inhabitants, these towns being near this canal. The commencement of this canal is in the estuary of the *Mersey* river at Runcorn-gap, and one of its terminations is the *Rochdale* canal at Castle Field in the town of Manchester, the other (or Worsley branch) is at Pennington near the town of Leigh, the junction of these branches being at Longford bridge; near Manchester there is a communication with the *Mersey and Irwell* navigation, and *Manchester Bolton and Bury* canal, by means of Medlock brook. Under the town of Manchester are arched branches of the canal of considerable length, from one of which coals are hoisted up by a coal-gin, through a shaft out of the boats below, into a large coal-yard or store-house in the main street, at which place the duke and his successors, are by the first act bound to supply the inhabitants of Manchester at all times with coals at only 4d. per cwt. of 140lb.; a circumstance which must have had a great effect on the growing population of this immense town within the last 40 years. At Worsley is a short cut to Worsley mills, and another to the entrance basin of the famous under-ground works or tunnels, of 18 miles or more in length in different branches and levels, for the navigation of coal-boats; some of which are as much as 60 yards below the canal, and others 35½ yards above the canal; these last, to which the boats ascend by means of an *inclined-plane*, that we have already described, extend to the veins of coal that are working at a great depth under Walkden Moor. Most of these tunnels are hewn out of the solid rock; from the lower one, the coals in boxes are hoisted up out of the boats, as they are in Manchester town mentioned above, and the whole of the lower works are prevented from filling with water, by large pumps worked by the hydraulic machine, which we have already mentioned in this article, and the water is thereby always kept at the proper height for navigation on the lower canal. Near Worsley, a branch of about 1½ mile in length, proceeds on to Chat-Moss and there ends, across which celebrated morals, it was by the first act intended to proceed, to the *Mersey and Irwell* navigation at Hollin Ferry near Glazebrook; but, like the cut proposed by the side of the *Mersey* to Stockport (7½ miles with a rise of 60 feet) was never executed, and the necessity for them is now in a great measure done away, by other plans which have been carried into effect. The rise of 82 feet in the first 600 yards from the *Mersey*, by 10 locks, is the only deviation from one level on this canal (except in the Worsley coal-mines above mentioned); and this length of level water is further increased; by 18 miles on the *Trent and Mersey* canal which connects therewith, making in all 70 miles of level. The width of the canal at top is 52 feet on the average, and depth 5 feet; the boats that navigate between Worsley mines and Manchester are only 4½ feet wide, the

others are 50 ton boats or upwards; there are also numerous boats for passengers; large warehouses have been built for goods, at the Castle Field in Manchester adjoining the canal.

Besides the tunnels under Manchester and at Worsley mines, we have been through a short one in passing a gentleman's house and a church, we think at Groppenhall. On this canal are three principal aqueduct bridges over the *Irwell* at Barton, where it is navigable, and over the *Mersey* and *Bollin* rivers, besides several smaller ones, and many road-aqueducts. There are also several large embankments, one over Stretford meadows, is 900 yards long, 17 feet high, and 112 feet wide at the base; that at Barton bridge is 200 yards long, and 40 feet high; at Bollington is also a stupendous embankment. The principal feeders for this canal are Worsley brook, and the mine-water there collected, the Medlock brook at Manchester, and the lockage of the *Trent and Mersey* canal; and water, which never was scarce in this canal, must now abound, since the increase of supply by the lockage of the *Rochdale* canal.

Mr. James Brindley, the engineer, owed much of his well earned fame to the happy contrivance and complete execution which he displayed in every part of this great concern; since the decease of Mr. Brindley, Mr. Gilbert and Mr. Benjamin Sothorn his Grace's agents, have done themselves great credit, by the masterly manner in which they have conducted the canal concerns of their noble employer, and improved and extended his works, as Mr. Thomas Bury has also in the mining department, so intimately connected therewith. The tunnelling at Worsley, and the canal between that and Manchester, were begun immediately on the passing of the first act; on the 17th of July, 1761, the Barton aqueduct was completed, and coals were soon after conveyed thereby to Manchester. On the 31st of December, 1772, the 10 locks at Runcorn were opened; in August, 1774, two packet-boats began to proceed regularly part of the way between Manchester and Liverpool, and on the 21st of March, 1776, the whole of the works which were then intended were finished; the extension to Leigh has been made since 1795. The illustrious *duke of Bridgewater*, justly styled the *father of British Inland Navigation*, died greatly lamented in March 1803, and left this immense concern, (which cost at first 220,000l. it was said, and probably in the whole twice that sum, as the tunnelling at Worsley alone has been estimated at 168,960l.,) to earl Gower, the present proprietor, whose second son is to inherit it; the net profits are said now to be from 50 to 80,000l. annually. The tonnage has not been increased since the first act, although the length of the canal has been increased to nearly four times what was at that time intended; boats may navigate the whole course or any part on paying 2s. 6d. per ton. Vessels passing out of the *Trent and Mersey* at Preston-Brook and into the *Mersey* at Runcorn, or the reverse, pay :d. per ton per mile for that distance; and all vessels passing to or from the *Rochdale* canal to this canal at Manchester are to pay, for paving stones 4d. per ton, and for all other articles 14d. per ton. It is provided, that flour shall not pay any tonnage on this canal, if the wheat whereof it was made had already paid. Irrigation, or watering of meadows, is practised in a very judicious and profitable manner, by water let out of this canal at Worsley and other places. The price of land-carriage for goods between Manchester and Liverpool was, on the passing of the Duke's third act, 40s. per ton, and by the navigation on the *Mersey and Irwell* 12s. per ton, but his Grace limited his price to 6s. per ton; yet, such has been the increasing trade of these two places, that it was in 1794

seriously maintained, and made the ground of another proposed navigable communication, by a junction of the *Manchester Bolton and Bury*, and the *Leeds and Liverpool* canals, that both the Duke's canal and the river navigation were inadequate to carry the trade between Manchester and Liverpool, and that the most frequent and ruinous delays were experienced by the merchants. In 1802, we find the idea again revived of a cut from the *Leeds and Liverpool* canal to the Leigh branch of this canal. About 1772, the *Liverpool and Runcorn* was proposed as an extension of this canal from Runcorn; in 1799, the *Manchester Bolton and Bury*, was proposed to be joined directly with this canal, by means of aqueducts over the Irwell and Medlock at Manchester.

Bristol and Gloucester. In the year 1797, we were told, that surveys were making of the line for a proposed canal from the Bath *Avon* at Bristol to the *Severn* at Gloucester, and also, of a continuation of the same across the Stratford *Avon* to the *Severn* at Worcester.

Bristol and Taunton. Several years ago, a canal was proposed, we are told, from the *Avon* river at Bristol to the town of Taunton, with cuts to Nailsea collieries, to the *Axe* river at Brean, and to the town of Langport, but we are not further acquainted with its objects or particulars.

BROTHIC RIVER. This is a small river on the coast of Angers county in Scotland, and navigable, we believe, but a small distance up from the harbour of Aberbrothick at its mouth, which harbour is of great antiquity, and appears to have had piers and works erected for its improvement and security, so long back as the year 1194; the spring tides here rise 15 feet.

Bude and Hatherleigh canal. In 1793, the *earl of Stanhope* proposed a line of water-levels and rail-ways, between the sea in Bude Haven, on the Bristol-Channel part of the Cornish coast, and the neighbourhood of Hatherleigh in Devonshire, passing the town of Holdfworthy, for carrying up sea-sand, (which in this bay consists of a congeries of broken shells), as a manure, and exporting of farming produce; the rise on this line was upwards of 500 feet, up which his lordship proposed, that his 2 ton boats should be conveyed at proper intervals on inclined-planes, whose peculiarities have been already mentioned in this article. In April last (1805), we find a scheme on foot, for improving the harbour of Bude and building a pier for the protection of ships.

Bude and Launceston, or the Tamar canal. This is one of the few instances, in which an act (14th of Geo. III.) was obtained, without any part of the scheme having been carried into effect. Mr. *Edmund Leach* the projector of this, in his *Treatise on Inland Navigation*, proposed, that it should proceed from the tide-way in Bude Haven, Cornwall, on the Bristol Channel, and proceed near to Launceston, and into the tide way in the river *Tamar* near Calflock, in the S.E. part of Cornwall. There was a provision, that the powers of the act were to cease in 10 years, if the canal was not proceeded with; it was proposed, to purchase only 39 feet wide of land, and not to be allowed to cut more than 39 inches deep into the earth on the lower side, in any part, except for docks, &c.; the canal to be 21 feet wide at top and 12 at bottom, with a towing-path on each side of it, 10 ton boats to be used; the direct distance of the two extreme points is only 28 miles, but owing to the extremely serpentine course of the level which was to be followed, its proposed length was 81 miles, and was estimated to cost 1000l. per mile. Locks were not to be used, but inclined-planes for boats of Mr. Leach's contrivance, of which we have already given an account in this article. From the sea at Bude, was to be a plane of 54 feet rise, thence a level of

6½ miles, then a plane of 120 feet rise, then 4 miles of level, and a third plane of 66 feet rise to the summit-level, which extended 34 miles to Launceston town, and 34 miles beyond; then, a plane with a descent of 120 feet, then 2½ miles of level, and a fifth plane, at Kelly Rock, of 120 feet fall to the *Tamar* navigation. A cut or feeder of 3 miles was proposed, from the *Tamar* is Lanells to St. Tankins on the Pack-saddle (being a low point on the south-western branch of the grand-ridge). Mr. Leach, however, tells us, that these levels are not to be entirely depended on, and mentions 258 feet as the elevation of the Pack saddle. The principal objects of this canal were the carrying of salt and shelly sand from the coast into the interior of the country as manure (an object since in part accomplished by the *Tamar manure*, and the *Stover* canals). In 1785, Mr. Leach wished to revive this project, and to shorten the course to 40½ miles, by cutting down the summit 18 feet, and making a tunnel of 100 yards; and to form another communication with the sea at Weedmouth-bay, where the same broken shells abound; the cost was now estimated at 53,100l.

BURROWSTOWNNESS CANAL. The act of the 8th of Geo. III. (for the *Forth and Clyde* canal) established a set of proprietors for this canal; its direction being nearly west for about seven miles in the counties of Linlithgow and Stirling, in Scotland; from the tide-way in the harbour of Burrowstownness, on the Firth of *Forth*, to the *Forth and Clyde* canal, near its eastern termination at Glangemouth. Its objects are stated to be, the avoiding part of a dangerous and difficult navigation on the *Forth*, and for improving the lands of Kinniel and Beercrofts, through which it passes. Burrowstownness, Linlithgow and Falkirk are considerable towns near this line. The depth to be seven feet, and width and size of the locks at the entrance proportionable thereto, the canal being level. The company are authorized to raise 8,000l. the shares to be 50l. each. The tonnage of lime, lime-stone, and iron-stone ½d. per ton per mile, all other goods and articles (except road-materials and manures) 1½d. per ton per mile.

BURRY RIVER. This river, or estuary, connecting with the Bristol Channel, is between the counties of Caermarthen and Glamorgan, in South Wales, and is navigable a distance of ten or eleven miles to Lwghor or Llougher, in nearly an east direction; at the flats in Llanelly it is joined by the *Caermarthenshire* rail-way, and another rail-way has lately been laid from this river to the Penclawdd copper-works: in 1801, the *Llandorrey and Llanelly* canal was proposed to join at the Spitty in Llanelly; and, in October 1805, a wet dock was proposed to be made on the east side of the Llanelly pier, to communicate with the *Caermarthenshire* rail-way.

Caerdyke. This is an artificial channel or ditch, as ancient as the time of the Romans in this country, from the *Nen* river, a little below Peterborough, to the *Wilham* river, three miles below Lincoln, of near 40 miles in length; it appears to have been very deep, though now almost grown up; and it is rather doubtful whether it ever was intended or used for the purposes of navigation.

CAERMARTHENSHIRE RAIL-WAY. Act 42 Geo. III.—The general direction of this line of rail-way is nearly north for 14 or 15 miles in Caermarthenshire; it commences on the coast, and is not very greatly elevated in any part; its general objects are the export of coals, iron, lead, &c. from the country through which it passes. Llandillo Vawr is the only considerable town near its course. It commences in the *Burry* river, at the new basin for ships, at the flats near Llanelly, and terminates at Castell-y-Garry line-works in Llanfihangel Aber-bythick. In the deep cuttings for

this rail-way near Mynydd Mawr several unknown veins of good stone-coal were discovered, and some of lead ore; in November 1804, the embankment near this place, consisting of more than 40,000 cubic yards of earth was completed, with the rail-way upon it. In October 1805, it was proposed to make a wet-dock for ships at the commencement of this line, on the east side of Llanelly pier; in 1801, the *Llandovery and Llanelly* canal was proposed to pass through nearly this line of country.

CAISTOR CANAL. Act 33 Geo. III.—The direction of this line is east 9 miles in the county of Lincoln; it is but little elevated above the sea. Its objects seem the importation of fuel and other articles, for the supply of Caistor town, and the export of farming produce: it commences in the *Ancholme* navigation, at South Kelsey, and terminates at the town of Caistor. The company were empowered to raise 25,000*l.*, shares 100*l.* The rates of tonnage are from 2*d.* to 8*d.* per ton per mile on different goods, with other rates for corn, &c. See *Phillips's 4to. History*, p. 47. All stores for the use of government, or materials for roads, to pass free at all times, and manures for the adjoining lands, when the waters run over the lock-weirs. In 1801, there was a proposal for extending this canal from Caistor, along the foot of the Woules, southerly, to Hambleton Hill, in Tealby, near Market-Raisin, the expence of which was estimated at 6,500*l.*

CALDER AND HEBBLE NAVIGATION. Act Geo. III.—The general direction of this navigation is nearly west, about 23 miles in length, in the west riding of Yorkshire; it has a considerable elevation above the sea at its west end: the general objects are the communication between Liverpool, Manchester, and Hull, by means of the *Rochdale* and *Huddersfield* canals, and *Ayre* and *Calder* rivers, the import and export of goods from Halifax, and the export of paving-stone (now so much used in London, called Yorkshire paving) from the famous quarries at Ealand-Edge and Cromwell-Bottom, and lime from Houghton, Brotherton, and Fairburn: at Cooper's Bridge it is joined by Sir John Ramsden's canal (leading to the *Huddersfield* canal), and at Dewsbury by the *Dewsbury and Birstal* rail-way. Halifax is the 58th British town, with a population of 8,886 persons; Wakefield the 64th, with 8,131 inhabitants; and Huddersfield the 81st, with 7,268 persons. This navigation begins in the *Ayre and Calder* navigation on the latter river, at Wakefield, and terminates in the *Rochdale* canal, at Sowerby-Bridge. There is a rail-way branch of about half a mile to Bradley collieries; it has a cut of about half a mile in length by the side of the Hebble river, to Salter-Hebble; and provision is made (in 33 Geo. III. for *Barnsley*) for a cut to Bargh-mill, on a branch of *Barnsley* canal; there are several locks; one of them near Salter-Hebble, of 10 or 12 feet rise, was in 1783 removed, and two new ones, of half that height, with a basin between them, were substituted by Mr. *William Jessop*; some of the locks here erected in 1761, by Mr. *Smeaton*, have single gates at their heads. At Salter-Hebble are a basin and large warehouses, and others at Sowerby Bridge, for the accommodation of the town of Halifax; near Ealand is a large weir across the *Calder* river. This navigation was planned or superintended by Mr. *James Brindley*, and afterwards by Mr. *John Smeaton*. About 1765, the navigation was brought up to Ealand quarries, and about 1776, to Salter-Hebble, and to Sowerby-Bridge warehouses. The stone and white slate from Ealand-Edge are carried in carts and four-wheeled carriages, to be put on board of the keels at Bridgehouse wharf, on account of the great height of the quarries above the *Calder*; the Cromwell bottom-stone is put on board at a wharf there. From the

quarries of *Thomas Thornhill, Esq.* at Lillon's Wood, near Ealand, a long and wide inclined plane, of about 45° of elevation, was, about the year 1774, made from the *Calder* river, and paved with large flat stones, on which a sledge descended loaded with stone, and by means of a rope passing over a wheel and axle, drew another empty sledge up the plane; this continued in use for some years; but this quarry was disused before the year 1783. In 1762, a violent flood happened on the *Calder* river, which destroyed many of the works thereon; these Mr. *Smeaton* repaired, and in 1774 another happened, so destructive that the navigation was for near a year suspended, before they were repaired; the fall of this river is no less than 8 feet per mile for more than 20 miles together. By the act 34 Geo. III. for *Huddersfield* canal, this navigation was guaranteed against a diminution of its tolls, by any other communication to the eastward opened therewith. In 1794, the *Manchester Bolton and Bury* canal was proposed to be extended to join this at Sowerby-Bridge. In 1802, the *Wilsley and Dewsbury* rail-way was proposed to join at Raven's Bridge, and notices have in the present autumn (1805) been given for the *Wakefield and Hullet* rail-way, intended to join this navigation at Bottom-Boat, near Wakefield; a side-cut is now making near Bridge-house, for avoiding the mill-dams, and improving this navigation.

CAM RIVER. The general direction of this navigation is about south-west, for 14 or 15 miles in the county of Cambridge; it is but little elevated above the level of the sea; its principal object is the supply of the town of Cambridge, which is the 51st in the order of our population, with 10,087 inhabitants: Ely also, near this navigation, is a considerable place. It commences in the great *Onse* river, at Harrimere, and terminates in the town of Cambridge. It has a cut or reach of 3 miles to Reche, and another of 3½ miles to Burwell, at which last place the *Bishopstortford and Wilton* canal was, in 1789, proposed to join. The *Cam* river is embanked above the adjoining fens through all its lower parts, is without locks in some parts, and has sluices for making flushes of water, to enable boats to pass the shallows and hard.

CAMEL RIVER. The general direction of this navigation is about south-east for near 8 miles, in the county of Cornwall; it is within the flow of the tide, and is chiefly used in the import of coals and export of agricultural produce: it connects at Guinea-Port, near Wadebridge, with the *Polbrock* canal. Padstow, on its banks, is a considerable town; it commences in the Irish channel, at Stepper Point, and terminates at Wadebridge.

Canterbury and Nicholas-Bay. In the year 1802, a canal was proposed, and again in 1804, and surveys taken, for a canal on a level, capable of carrying sea-built vessels, between the sea at St. Nicholas Bay, near Margate, to the city of Canterbury, about 10 or 11 miles in a south-west direction, there to connect with the *Stour* river, and with a canal then proposed, called the *Medway and Rotter* canal. Canterbury has 9000 inhabitants, and is the 57th place in the order.

CARDIFF AND MERTHYR-TYDVIL RAIL-WAY. Act about 35 Geo. III.—This line is nearly in a north-west direction, for 26½ miles, in the county of Glamorgan, in South Wales. The general object of this rail-way is the export of iron from the great works at Merthyr Tydvil, Dowlais, &c. Cardiff, Caerphilly, and Merthyr are considerable towns on or near this line, which commences at the floating-dock, in the *Severn* at Lower Layer, the termination of the *Glamorgan and Breck* canal, by the side of which, very nearly, it proceeds to Merthyr Tydvil, and thence to the lime-works at Panton, in Merthyr parish; at Quaker's yard a branch of

9½ miles goes off to Carno mill, in Bedwellty; *Honfray, Hill and Co.* are the proprietors of this rail-way or tram-road, and it was, we believe, constructed under the first act of parliament ever passed for this kind of roads; the width of land allowed to be purchased was 7 yards. On the 21st Feb. 1804, a trial was made of one of Trevethick's high-pressure steam-engines for drawing trams on this tram-road, as before mentioned, and 10 tons of iron and 70 persons were drawn for 9 miles by the power of steam, without the use of condensing-water. At Merthyr there is a curious and stupendous water-wheel, of 50 feet diameter, made of cast-iron.

CARON RIVER. The direction of this river is west, in the county of Stirling, in Scotland, and for 3 miles it is navigable, from the *Forth* river to Caron shore, for vessels drawing 7 or 8 feet water at neap-tides; at Caron shore there is a cut from the *Forth and Clyde* canal; and near Caron shore are the famous Caron iron-works.

CART RIVER. The direction of this navigation is nearly south, for about 3 miles in Renfrewshire, in Scotland; its objects being the supply, and the exports and imports of the great manufacturing town of Paisley, which is the 15th in the order of British towns, and contains 31,179 persons. Renfrew is also a considerable town near the same: this navigation commences in the *Clyde* river, near Inchinnan, and terminates at the town of Paisley, at which place it was proposed, in 1803, to be joined by the *Glasgow and Saltcoats* canal.

CHELMER AND BLACKWATER NAVIGATION. Acts 6 and 33 Geo. III.—The general direction of this navigation is nearly west for 1½ miles in the county of Essex; its general objects are the supply of Chelmsford and its neighbourhood with coals, deals, &c. and the export of farm produce. It commences in the Tide-way, at Collier's-Reach, in the estuary of Blackwater river, and proceeds by the course of the Chelmer river to the basin at Chelmsford town, with a cut near ¼ of a mile to Malden. Chelmsford and Malden are considerable towns. From low-water in the basin at Collier's reach to Heybridge-mill, on Blackwater river, 1½ mile, is a rise of 12 feet 8½ inches, thence to Beely or Bailly-mill, on Chelmer river, 1½ mile, is a rise of 7 feet 3½ inches; thence to the basin at Chelmsford is 10½ miles, with a rise of 59 feet 5 inches: the branch has a rise 6 feet 8½ inches into the basin at Malden. Mr. *John Smeaton* surveyed this line in 1762, and recommended 13 miles of new canal, and estimated the same at near 16,700l.; Mr. *John Rennie* was afterwards employed. The basin at Collier's reach was opened for ships in February 1796; the company were authorized to raise 60,000l. the amount of shares 100l. each; in 1802 these were so depreciated, that they were said not to be worth 5l. each. The spring-tides flow 5 feet at Bailly-mill-tail, and 8 feet at Malden bridge; the neap tides do not raise the water above one foot at the last place.

Cheltenham and Tewksbury. In 1801, notices were given for a proposed canal from the *Severn* river, near the junction of the *Avon* therewith, at the town of Tewksbury, to the town of Cheltenham, through the parishes of Tewksbury, Tredington, Elmstone-Hardwick, Uckington, Swindon, and Cheltenham, a course nearly south-east for about 8 miles, in the county of Gloucester. Tewksbury and Cheltenham are considerable places.

CHESTER CANAL. Acts 11 and 17 Geo. III.—The general direction of this canal is about south-east for 18 miles, in the county of Chester; it is not greatly elevated above the level of the sea; its principal objects are the export of farming produce, and the import of coals and lime for Nantwich town, and the surrounding country; it forms a double

communication between two points in the line of the *Ellefmere* canal, at Chester and at Franckton common. Chester is the 25th British town, with a population of 15,052 persons. Nantwich is also a considerable town. This canal commences in the tide-way in the *Dee* river, in the town of Chester, near to where the *Ellefmere* canal crosses the same, and terminates at the town of Nantwich; at Stoke, in the parish of Acton, it is joined by the Whitechurch branch of the *Ellefmere* canal; from Chester to Barbridge, near Tiverton, the distance is 14½ miles, with a rise of 170 feet 10 inches, and thence to Nantwich it is 3½ miles, and level. The canal passes Christleton, Waverton, Hargrave, Huxley, Brassley green, Beerton-castle, Tiverton, Hurleston, Acton, and Nantwich; there is an aqueduct at Huxley-mill. Mr. *James Brindley*, and other engineers, were employed in 1767, 1769, and 1770; in 1769 an unsuccessful attempt was made to obtain an act for it; it was begun in 1772, and was completed from the *Dee* to Huxley-mill 16th June 1775, and shortly after to Nantwich; a branch was provided for in the act, from Barbridge, 8½ miles long, with a fall of 40 feet, to Middlewich, near to the *Trent and Mersey* canal, but not into it. Although this branch, intended for bringing salt to Chester, was not executed, the expences amounted to 80,000l. and the shares became perhaps the most depreciated of any concern in the kingdom, being sold at one time, as we are informed, for one per cent. of their original value. In 1793, a junction was proposed near Nantwich, with a branch of the intended *Sandbach* canal; in 1793, a rival scheme to the *Ellefmere*, called the Eastern Grand Trunk, was proposed to join at Crows-nest; and in June 1796 the *Commercial* canal was proposed to join at the same place, in order to form by means of the *Ashby-de-la-Zouch* canal, and others, a communication for 40 ton boats, between Liverpool, Chester, Hull, London, &c.

CHESTERFIELD CANAL. Act 10 Geo. III.—The general direction of this canal is nearly south-west, by a crooked course 46 miles in length, in the counties of Nottingham, York, and Derby; the western end is considerably elevated; its principal objects are the export of coals from near Chesterfield, and lead from the Derbyshire mines, and the import of lime, corn, timber, &c. Chesterfield, Workfop, and Retford are considerable towns upon this line, which commences in the *Trent* river, near its junction with the *Idle* river, at Stockwith, and terminates at Chesterfield town; from the *Trent* to Workfop the distance is 24 miles, with a rise of 250 feet; thence to Norwood it is 9 miles, with a rise of 85 feet; and thence to Chesterfield it is 13 miles, with a fall of 45 feet: the number of locks is 65; the lower part of the canal, from the *Trent* to Retford, is for large boats of 50 or 60 tons burthen; above this the width is 26 to 28 feet, and depth of water from 4 to 5 feet; the boats here used being 70 feet long and 7 wide, and carrying 20 to 22 tons each. In 1794 such boats as these cost, when new, 90 to 100l. each. The boat-owners here usually pay their bargemen by the ton of goods which they convey stated distances, instead of weekly wages. At Norwood is a tunnel through Hartshill of 2850 yards in length, being 12 feet high and 9½ wide within the arch, and 36 feet below the surface of the hill; this tunnel was begun in November 1771, and finished the 9th May 1775; at Drake's-hole is another tunnel of 153 yards in length. Mr. *James Brindley* projected this canal, and directed its execution until his death in September 1772, when his brother-in-law, Mr. *Henshall*, succeeded, and completed the whole in 1776. The tonnage is 1½d. per ton per mile, and in calculating the same ¼th of a mile is taken into account, and ¼th of a ton. It appears that the canal cost 160,000l. and the shares were at first much depreciated, and sold for a long

time below par; in September last (1805) the profits amounted to 61. per cent. annually. In Mr. *Brindley's* time, a junction was intended at Chesterfield with the proposed *Chesterfield and Swarkestone* canal; and in 1802, an extension of this canal was proposed of 5 or 6 miles in length, nearly south to Ashover.

Chesterfield and Swarkestone. The late Mr. *Brindley*, about the year 1771, proposed a canal from the *Trent and Mersey* canal at Swarkestone to the *Chesterfield* canal at the latter place, the direct distance being about 25 miles nearly north, the line being through a country very rich in coals. Derby, the 43d town, with 16,832 inhabitants, was to be in the line of this canal, and the town of Belper is also near it.

CHICHESTER HAVEN. This inlet of the sea, on the coast of Hampshire, is of considerable length, in different branches, navigable for ships, surrounding Thorney Isle, and connecting with Langstone and Portsmouth harbours. Havant and Chichester are considerable towns near it. In September 1805, notices were given for cutting a short canal, to commence with a sea-lock in deep water in this haven, and proceed to Upper Southgate field, in Chichester, there to terminate in a spacious basin or dock.

CLEBY RIVER. This river has nearly a north-east course, in the county of Pembroke, in South Wales. It commences in the tide-way in *Milford Haven*, and terminates at Canniffel bridge, near Narberth, which is a considerable town; and Pembroke on another branch of the haven is also a considerable place.

CLYDE RIVER. Acts 34 Geo. II. and 9 and 11 of Geo. III.—This river or frith commences with a most noble and capacious estuary, in the northern or Irish channel, and extends nearly north, to Gonrook, when its direction changes towards the east, and its width diminishes gradually to Glasgow, where the navigation terminates. Glasgow is the 5th town in Britain, in point of population, containing 77,385 inhabitants: Paisley, in the vicinity of this river, is the 15th town, with 31,179 persons; Greenock, the 20th, with 17,458 persons; and Rothsay, (on the Isle of Bute) the 18th, with 5,281 persons: Rutherglen, Renfrew, Dumbarton, Port-Glasgow, Irvine, and Ayr, are also considerable places on or near the banks of this river. At Glasgow basin a branch of the grand *Forth and Clyde* canal joins this, as also the *Monkland* canal, and *Edinburgh and Glasgow* canal; near Inchinnan the *Cart* river joins, and at Dalmure Burnfoot; the western termination of the *Forth and Clyde* canal is in this river; while the navigable lochs and fountains which connect therewith below Dumbarton are both numerous and important; by means of lochs, Fine, and Gilp, there is a connection with the *Crinan* canal. In the year 1805 an act (45 Geo. III.) was obtained by the earl of *Eglinton* and others, for building new piers and improving *Ardrossan* harbour, and building wet-docks, &c. near Saltcoats, on this river, and in this harbour, as well as at Glasgow, the *Glasgow and Saltcoats* canal was, in 1803, proposed to connect therewith; at Rothsay, on the Isle of Bute, piers have been built, and the harbour connecting with this river improved; *Greenock* harbour is also under great improvement, in consequence of an act of 43 Geo. III. The trade on this river is very immense and various; it appears that Greenock alone employed 175,551 tons of shipping thereon in the year 1800.

CODBECK BROOK. Act 7, Geo. III.—The direction of this navigation is nearly north for about six miles, in the north riding of Yorkshire, commencing in the *Sewale* river near Topcliff, and extending to the town of Thirsk, for whose accommodation it is intended.

COLNE RIVER. The general direction of this navigation

is nearly N.W. for about 8 miles, in the county of Essex; its objects are the import of coals, deals, &c. and the export of farm produce, and of oysters from the banks below Wivenhoe. Colchester is the 39th place in Britain, with a population of 11,520 persons. It commences with an estuary at Mersey island, and terminates at the town of Colchester, to which place small sea-built vessels can get up. Large ships navigate to Wivenhoe, where there is a dock-yard for building frigates and large trading ships.

ST. COLUMB CANAL. The general direction of this canal is nearly east for seven or eight miles, in the county of Cornwall; although near the coast, it is considerably elevated. Its objects are the export of a particular species of stone found about St. Dennis, called China-stone, used in great quantities in Wedgewood's, and other potteries near the line of the *Trent and Mersey* canal, and the import of coals, and of a sea-sand consisting of broken shells for manure. This canal was proposed to proceed across the western branch of the grand ridge to the south coast; not one third of which length has, however, been carried into effect. St. Columb Major, St. Austel, and Grampond, are towns near the line. It commences at the sea-shore of the Irish channel near St. Columb Minor, and terminates at present within about two miles of St. Columb Major; from thence it was to pass St. Dennis, St. Stephen, St. Ewe, and arrive at the sea again near Pentuan, not far from the famous Polgarth mines and engines. The part which was completed about the year 1775, commenced on the top of a very high cliff, and pursued the course above mentioned, without locks, we believe. The canal was a narrow one, and at its west end, the cliff was with great labour hewn down, into a steep inclined plane, that was covered with planks: the canal was conducted to the very top of this plane, and the boats which were rectangular ones, were brought, when loaded with stone, to the termination of the canal, where they were fastened by a sort of hinges; strong ropes were then attached to the stern of the boat, and by means of a wheel and drum, worked by a horse-gin or wem; the boat was hauled up an end, and the stones were thereby shot out, and rolled down the plane to the strand below, from whence boats conveyed them on board the ships. The same wheel and drum was adopted for drawing boxes of coals or Shelly sand up the plane, in order to their being loaded into the returning boats. Near to its eastern termination the canal was conveyed on an aqueduct bridge over a road. We have been favoured with these particulars by a Cornish gentleman, since our account of inclined planes was written, or we should have noticed this (the plane on *Parnel's* canal and another on the *Culder and Hobble*) as early instances of the use of inclined planes for boxes of goods, &c. For seven or eight years this canal continued in use, but whether like the *Mawgan* canal, in its neighbourhood, it has since been disused, we are not at the present moment able to learn.

Commercial Canal. In the year 1796, Mr. *Robert Whitworth* was employed to survey this line, proceeding from the *Chester* canal at Nantwich to the *Abbey de la Zouch* canal near that town; it was proposed to join Sir *Nigel Grifley's* canal and the *Newcastle under-line* canal, to cross the *Trent and Mersey* canal near Burslem, and proceeding by Uttoxeter, to cross the *Trent and Mersey* canal again, and the *Trent* river at Burton. The objects of this proposed canal were, the forming of a communication for larger boats (40 tons) than the *Trent and Mersey* is calculated for, except below Burton, and contributing towards the wished-for passage of large boats between Liverpool, Manchester, Chester, Hull, London, &c.

CONWAY RIVER. This river has nearly a south course for

14 or 15 miles, between the counties of Caernarvon and Denbigh in North Wales; its principal object seems to be the supply of Llanrwst and Aberconwy, which are considerable towns. It commences at the tide-way in Conway bay, and terminates at Llanrwst town. In June 1802, it was in contemplation to straighten the course of this river, about a mile below Llanrwst, by a new cut 492 feet long, 88 feet broad at top, and 65 at bottom, with a dam at its upper end across the old crooked channel. At Llanrwst, there is a curious stone bridge of three arches, built by *Inigo Jones*, over this river; and in 1803, it was proposed to construct a stupendous cast iron bridge over it at Aberconway ferry, in order to facilitate the communication with Ireland by way of Holyhead, in the Isle of Anglesea; another iron bridge being intended at Bangor ferry, on *Menai* strait.

COOMBE-HILL CANAL. Act 32 Geo. III.—The course of this canal is nearly S. E. for $3\frac{1}{2}$ miles, in the county of Gloucester: its general objects are the export of coals from the mines near it, and shortening of the length of land carriage to Cheltenham, which is a considerable town; and so is Tewksbury near its western end. It commences in the *Severn* river at Fletcher's leap in Dearhurst, and terminates at Combe hill in the parish of Leigh, the rise being 15 feet only. This canal was constructed at the sole expence of three persons, viz. *Thomas Burges*, *William Miller*, and *Sarah Mumford*.

Cottingham and Hull. In the year 1802, this line of canal was proposed, about four or five miles in length, in a N.W. direction, in the east riding of Yorkshire, to commence in the *Humber* river at the town of Hull, and extend to the town of Cottingham. The import of coals, deals, &c. and the export of farm produce, and perhaps of chalk, seem to be its principal objects. Hull is the 16th town in Britain, with a population of 29,516 persons.

COVENTRY CANAL. Acts 8, 25, (for *Trent and Mersey*) and 26 of Geo. III.—The general direction of this canal is nearly S.E. for about 22 miles (exclusive of the detached part beyond the *Birmingham and Fazely* canal, and the branch to Coventry) in Staffordshire and Warwickshire. Its situation is high, particularly the eastern part, which crosses the grand ridge near Bedworth, without a tunnel, and its Seefwood branch does the same. Its general objects are the line of communication between London, Birmingham, Manchester, Liverpool, &c. the export of coals from the numerous mines near it, and the supply of Coventry city, which is the 24th on the list of British population, with 16,034 inhabitants. Nuncaton, Atherstone, and Tamworth, are also considerable towns near the line; and Hinckley, the 120th, with 5,070 inhabitants, is also in its vicinity. It commences in the *Birmingham and Fazely* canal at Fazely, and terminates in the *Oxford* canal at Longford; its detached part of $5\frac{1}{2}$ miles in length, commences at the termination of the *Birmingham and Fazely* canal at Whittington brook, and terminates in the *Trent and Mersey* canal at Fradley heath; near to Whittington brook, it connects with the *Wyre and Effington* canal, and at Marston bridge the line is joined by the *Asby de-la-Zouch* canal. There is a cut of about one mile in length to Griff collieries, belonging to sir Roger Newdigate; another to several collieries by different branches near Seefwood-pool and Bedworth, five or six miles in length; there is also a cut of half-a-mile from the line to Bedworth; the branch to Coventry is $4\frac{1}{2}$ miles in length, and there is a rail-way branch to Oldbury coal works. The detached part is level with the *Trent and Mersey* canal, which level continues (through $5\frac{1}{2}$ miles of the *Birmingham and Fazely*) to the commencement of the line of this canal at Fazely; from thence to Atherstone, a distance of about

10 miles, the rise is 96 feet, by means of 13 locks; from thence to the *Oxford* canal, about 12 miles, is level; so is the cut to Coventry, and those to Griff, Seefwood-pool, Bedworth, &c. The last or highest level of this canal forms, with part of the *Oxford* and *Asby* canals, the longest level that is to be found in Britain, being upwards of 82 miles, we believe, including side branches. This is a narrow canal, but the company have bound themselves to widen the same to the width of the *Grand Junction*, if the proprietors of that canal shall at any future time require it. A stop-gate is maintained at the end of the *Oxford* canal at Longford, to prevent this canal, which is sometimes low in Summer, from drawing off their water. Mr. *James Brindley* was the original engineer to this concern, and $16\frac{1}{2}$ miles of the level part from Coventry to Atherstone was completed in 1786, when the works were suspended for near 10 years; at length, the *Trent and Mersey* company undertook to complete 11 miles of this original line north of Fazely; half of which they afterwards sold to the *Birmingham and Fazely* company; and the other half, on the 4th of February, 1787, was purchased by this company, who thus came to have a detached part of their canal. The line of communication was opened by the completion of this canal in June 1790. This company have been authorised to raise 120,000l., their shares being 100l. each. Some years after the completion of this and the *Oxford* canal, the shares herein had obtained the great price of 400l., but owing to the rivalry of the *Warwick and Napton* canal, they were, in 1802, reduced to 350l., and their dividend to 8l. per cent. Since the completion of the *Grand Junction*, this concern has been flourishing, and the dividends are now 16l. per annum per share. The tonnage allowed on this canal is $\frac{1}{2}$ d. per ton per mile for lime and lime-stone, and $1\frac{1}{2}$ d. per ton per mile for all other articles, (except road or paving materials and manures upon the pounds, or when the water runs to waste at the locks.) On the completion of the adjoining canals, the tonnage on coals was, by their general consent, reduced to 1d per ton per mile upon several of them. It was agreed, between this and the *Oxford* company, (9 Geo. III. *Oxford*) that the latter should be entitled to all tolls, except on coals, that are collected on the first $3\frac{1}{2}$ miles of this canal towards Coventry, for goods passing from the *Oxford* canal, and that this company should in return receive the tolls upon coals collected on the first 2 miles of that canal. The act of 34 Geo. III. for *Asby-de-la-Zouch* canal, granted to this company 5d. per ton upon all goods (except farming produce, manures, or road materials, or iron or its ore, made or dug on the banks of the *Asby* canal) navigated thereon, which shall, either before or after, pass on any part of this canal, or the *Oxford* or *Grand Junction*; and a farther sum per ton, equal to the tonnage hereon between Griff and Longford, on all goods which may pass any new communication that may hereafter be opened between the *Asby* canal and the *Oxford* or *Grand Junction*; for enforcing which, this company is empowered to erect toll-houses and stop-bars, and place collectors on any part of the *Asby* canal.

CREE RIVER. The course of this river is nearly north, for 9 or 10 miles of a crooked course, between the counties of Wigton and Kirkcudbright in Scotland; its object is the supply of the adjoining country, and of Wigton, which is a considerable town. It commences in the tide-way in Wigton bay in the Irish or Northern Channel, and terminates at Newton Douglas.

CRINAN CANAL. Acts 33, 39, and 45 of Geo. III.—The course of this very wide and deep canal is nearly west for about nine miles, in the county of Argyle in Scotland; its sole object is the shortening of the passage for ships be-

tween the Irish Sea and the *Clyde* river (by means of the loch of Fine), by avoiding the voyage round the peninsula of Kintire. It commences at lock Gilp, and terminates in lock Crinan. The rise is 58 feet, and the fall 59 feet, a rivulet near the point of division serving as its feeder. The water in this canal is 12 to 15 feet deep. This line of canal was first surveyed for smaller vessels by Mr. Watt, after which Mr. John Rennie was employed herein; it appears to have been opened some time, but farther improvements, and the building of a pier in Loch Gilp are yet in hand. The proprietors have been authorised to raise 180,000*l.*, and they have also received 50,000*l.* of the public money, which parliament granted in aid of this great and important work. The shares are 50*l.* each. A vessel under sail, not being stopped in proper time, before she arrived at a lock on this canal, bore the same away, and went down therewith into the next pound. A passage may, it is said, be made by means of this canal in three or four days, which frequently took up three weeks. In 1802 the shares herein were 22*l.* below par.

CROMFORD CANAL. Act Geo. III.—The general direction of this canal is about N.W. for 18 miles, in the counties of Nottingham and Derby; it is considerably elevated: its general objects are the export of coals and of lead, iron, lime-stone, and other minerals from the mines of Derbyshire. Wirksworth and Belper are considerable towns near its course. It commences in the *Erewasb* canal at Langley bridge (not far from the junction of Nottingham canal therewith), and terminates in the town of Cromford near Matlock. There is a cut to Pinxton coal works of three miles in length, another to Swanwick coal works; also a rail-way branches to Critch lime-works, $1\frac{1}{2}$ mile, and to Biggarlee coal works $1\frac{1}{4}$ mile. From the *Erewasb* canal to near Codnor castle, four miles, there is a rise of 80 feet, thence to Cromford, 14 miles, it is level; the Pinxton branch is level, and proceeds from the upper level. The width of this canal at top is 26 feet; the boats are 80 feet long, $7\frac{1}{2}$ feet wide, and $3\frac{1}{2}$ feet deep; when empty they draw 8 or 9 inches of water, and when loaded with 22 tons, they draw about $2\frac{1}{2}$ feet. Near Ripley is a tunnel of 2966 yards in length, which is 9 feet wide within side at the water's surface, and 8 feet high from thence to the crown of the arch, which is of brick, except some parts where the rock proved hard and sound enough to stand without walling: the side-walls and crown of this arch seem to be part of an ellipsis, but where an inverted or bottom arch was wanted, the same is much flatter. For constructing this tunnel, 33 pits or tunnel-shafts were sunk, some of them on the summit of the hill, being 57 yards deep. This tunnel is said to have cost 7*l.* per yard in length: it intersects a valuable seam of coals, which is now worked, and in sinking the tunnel-pits excellent iron ore was found, which is now worked, and the furnaces are supplied with coals drawn up through a shaft from below for that purpose. There are several smaller tunnels upon the line for shortening its course. Near Butterly hall there is a considerable deep-cutting, and shorter ones in other places, to avoid the loops round the points of the hills. Over the Derwent river, near Wigwell, there is a large aqueduct bridge 200 yards long and 30 feet high, the river arch is 80 feet span. Two smaller arches by its side serve to carry off floods, and for a road. Over a small river, which comes into the Derwent near Frithly, is another large aqueduct bridge about 200 yards long and 50 feet high; besides the river arch, there are two others, one for floods, and another conveys the turn-pike road under the canal; these two aqueducts are said to have cost about 6000*l.* There are considerable embankments in some places on this canal. Nearly

over the Ripley tunnel there is a reservoir of 50 acres of water when full, the head or embankment of which is 200 yards long, 33 feet in height in the middle of the valley, the base being there 52 yards wide, the top of the bank is four yards wide. This reservoir is said to have cost 1600*l.*; the mean depth of it is 12 feet, and it will contain about 2800 locks full of water, which is let out by a large pipe and cock in one of the tunnel-pits. There are two other reservoirs for this canal, one of 20, the other of 15 acres. At the Cromford end of the canal there is a considerable stream of water taken in as a feeder, and the whole of the 14 miles of level and branches thereto have their banks made up one foot higher than usual to act as a reserve for dry weather. Mr. William Jessop was the engineer to this canal, and it was completed before the year 1794. The total cost is said to have exceeded 80,000*l.* For the cutting and wheeling of clay, $3\frac{1}{2}$ d. per cubic yard, per stage of 20 yards, was usually paid; for gravel $4\frac{1}{2}$ d. per yard; for stony ground $4\frac{1}{2}$ d. per yard, and 4d. per cubic yard extra for all stones picked out and flacked. In the year 1797, a cut was proposed from the summit-level to the new collieries in Codnor park. In 1801, notices were given for the intended *Belper* canal, that was proposed to join this near to Bull bridge; and in 1802, a cut was proposed to be made from the Derwent aqueduct on this canal to near Dethick, and thence near the Derwent and Wye rivers to the town of Bake-well.

CROUCH RIVER. The course of this river is nearly west, in the county of Essex. The principal objects of this navigation are the import of coals, deals, &c. and the export of farm produce, and of oysters from near Waltham. Billerica and Rochford are the nearest considerable towns to this river. It commences in the English channel (about 10 miles from the mouth of the *Thames*), and terminates at Hull bridge.

CROYDON CANAL. Act 41 Geo. III.—The general direction of this canal is nearly south for $9\frac{1}{2}$ miles, in the counties of Kent and Surrey: it is not greatly elevated; its objects are the supply of Croydon with coals, deals, &c. and the country through which it passes with manures and other articles, and the conveyance of its produce to the London markets, and the export of fire-stone, flint, and fullers' earth. Croydon is the 108th British town, with a population of 5,743 persons. Deptford is also a considerable place. This canal commences in the *Grand Surry* canal near Deptford (two miles from its connection with the *Thames* at Rotherhithe), and terminates at the new Bason near the town of Croydon. From the *Grand Surry* canal (level with an ordinary high tide in the *Thames*) to the top of Plowgarlick hill, $1\frac{1}{2}$ mile, is a rise of 70 feet, by 12 locks; thence for $\frac{1}{4}$ a mile it is level, and thence for $\frac{1}{4}$ of a mile to the beginning of Forest wood, there is a rise of $79\frac{1}{2}$ feet, by 13 single and one double locks; from thence to Croydon, 7 miles, it is level. The locks upon this canal are 60 feet long and 9 feet wide; each lock has a groove for stop-planks at its head, but no paddle-weirs; the waste water is intended to run over the upper gates. This company are to have a bason for their boats to lie in at Rotherhithe, on the south-east side of the *Grand Surry* entrance bason, and another by the high road near Croydon town. There are seven road bridges and 30 accommodation swing-bridges. On the top and northern slope of Plowgarlick hill, there is a considerable deep-cutting, and others in Sydenham and on Penge common; and near Selhurst wood is a considerable embankment. On Sydenham common there is a reservoir of 10 or 15 acres supplied in wet times by a feeder out of an adjoining vale, and into which its waste or over-fall is to be when full; there is

another reservoir on Norwood common, which, with the long summit-pound on so tenacious a soil, will be sufficient, it is presumed, to supply the locks that are making. At the time the act passed for this canal, it seemed intended to use inclined planes, and to pump the water for supplying the pounds up from the *Grand Surry* canal by steam-engines, that were also intended to wind the boats up the planes; and it seems singular, under these circumstances, that legislative provision was made, for a culvert or small tunnel through Forest-hill for conveying water from the summit-level of this canal on Sydenham common, and by aqueducts or pipes to supply several towns and places with water, viz. by a branch of near $\frac{3}{4}$ of a mile to the top of Dulwich town, and from the end of the said tunnel to Knight's hill by a crooked course of three miles in length through Norwood, and along Knight's hill towards London for one mile; also another branch of near one mile to Streatham town. Mr. *John Rennie* and Mr. *Ralph Dodd* were the engineers, and Mr. *Clark* is now employed as resident engineer thereon. About seven miles of the upper end of this canal is completed and in use, and the remainder is proceeding with great expedition. The company are empowered to raise 80,000*l.*, which is not now expected to prove sufficient; the amount of shares are 100*l.* each. The sum of 40*l.* is to be paid annually to the city of London, towards improving the Thames river above London Bridge. This canal is to have its water kept always two feet above the surface of the ground on Croydon common, and some other severe and unprecedented restrictions are introduced in favour of the millers on the Wandle river, at some miles distance.

Croydon and Wandsworth. In September 1800, proposals were made for a canal from the river *Thames* at Wandsworth, following nearly the course of the Wandle river to Croydon in Surry; but the same was given up shortly after, in favour of the north *Surry iron rail-way*, which passes through nearly the same tract.

CYFARTHFA CANAL. The general direction of this canal, or *water level*, is nearly N.W. we believe, for about 3 miles, in the county of Brecknock; it is on a high level, and was constructed some years ago by Mr. *Bacon*, to bring coals and iron-ore from the mines in the mountains, to his furnaces at Cyfarthfa, near Merthyr Tidvil. The whole is upon one level, and it does not connect with any other canal or navigation; it is now the property of Mr. *Crawshaw*, the great iron master. It is situate near to the northern ends of the *Glamorganshire* canal and the *Cardiff and Merthyr rail-way*.

DARENT RIVER. The course of this river (called Dartford creek,) is south for near 3 miles in the county of Kent; it commences in the tide-way in the river *Thames*, and terminates near the town of Dartford, for whose supply it is principally used.

DART RIVER. The general direction of this river is nearly N.W. for about 10 miles, in Devonshire; the tide flows through its whole length; its principal objects seem to be the supply of Totnes with coals, and the country with shell-fish and manure, and the export of farming produce. Dartmouth and Totnes are considerable towns; its commencement is in Start bay, and it terminates at the Mill weir, about one mile above Totnes; this river is plentifully stored with trout.

Dean-Forest Rail-way. In the year 1802, it was proposed to construct a rail-way from the river *Wye*, near to English Bicknor, we believe, to the summit of the Forest of Dean, its object being the carriage of the immense stores of coal and iron, with which it abounds; Colford is a considerable town near its route. In the preceding year the *Severn and Wye* rail-way was proposed to pass nearly the same track.

DEAN RIVER. Act 12 Geo. III.—The direction of this

river is nearly S. for about 2 miles, in the county of Nottingham; it is not greatly elevated above the level of the sea; its principal object is the supply of Newark, the 9111 town in the list of British population, with 6730 inhabitants. It commences in the river *Trent*, at Crankley's, in South Markham, and terminates at the upper weir near the town of Newark; the works hereon were completed in Jan. 1797. In 1793 the *Newark and Bollesford* was proposed to join this at Newark.

DEARNE AND DOVE CANAL. Acts 33 and 40 Geo. III.—The general direction of this canal is about N.W. for $9\frac{1}{2}$ miles, in the West Riding of Yorkshire, its northern end is considerably elevated; its objects are the communication between Sheffield, Wakefield, Halifax, Leeds, Manchester, Liverpool, &c. and the export of the coals and iron-stone, &c. so plentifully found on its course. Barnsley and Rotherham are considerable towns on or near it, so is Doncaster, the 11011 town, with 5697 inhabitants. It commences in a side cut of the *Don*, or *Dun* river, between Swinton and Mexburgh, and terminates in the *Barnsley* canal at Eyming's wood, near Barnsley, there is a branch of $3\frac{1}{4}$ miles to Rockcliff bridge, and another of $1\frac{1}{2}$ miles to Cobcar Ing. From the cut of the *Don* navigation to Knoll Brook the distance is $4\frac{1}{2}$ miles, with a rise of $41\frac{1}{2}$ feet; thence to Aldham Mill, $2\frac{1}{2}$ miles, is a rise of 24 feet, (the Cobcar Ing branch being on its highest level); thence to the *Barnsley* canal is $2\frac{3}{4}$ miles, with a rise of $59\frac{1}{2}$ feet; the Cobcar Ing branch is level; the Rockcliff branch begins from the summit-level, and $1\frac{1}{2}$ mile to Worsborough bridge is level; thence to Rockcliff bridge, $1\frac{1}{2}$ mile, it has a rise of 56 feet. The locks on this canal are built with excellent hewn or ashler stone, and are calculated for boats of 50 or 60 tons burthen, the same as navigate the *Dun* river, and this company are required to keep a depth of water equal to $4\frac{1}{2}$ feet on their lock-fills, and in every part of their line; and for guarding against loss of water on the summit, a stop-gate is to be erected hereon, near the termination in the *Barnsley* canal, and another on that canal below the junction, both of which may be shut and locked when the supply of either canal fails, and it would consume the water of the other. The aqueduct and other bridges hereon are substantially constructed of hewn stone. Tumbling-bays and gauge-weirs are to be erected for supplying several mills. There is a large reservoir near Ellicar. Proprietors of mines may make rail-ways to this canal, if within 1000 yards, or 2000 yards near Wath. Mr. *John Thompson* is said to have been the engineer, and it was completed in the year 1804. The company were empowered to raise 100,000*l.* The amount of shares 100*l.* each. The rates of tonnage on this canal are too various and complicate for the room we can allot to this subject, they will be found in *Phillips' 4to. History*, p. 62 to 66; but it must be observed, that the last act (40 Geo. III.) made an increase of, we believe, 50 per cent. on these tolls. Boats are to pay for 6 miles of tonnage, however short a distance they may have navigated on this canal. In May 1797, earl Fitzwilliam proposed, at his own expence, to extend the Cobcar Ing branch to his Ellicar collieries, on being allowed water for the same from the Ellicar reservoir.

DEBEN RIVER. The course of this river is nearly N.W. for about 10 miles, in the county of Suffolk; its objects are the imports of coals, deals, &c. and exports of farm produce; it commences at the sea near Felixtow, and terminates near Woodbridge, which is a considerable town.

DEE RIVER, (Aberdeen). This river takes its course about west for 2 miles, between Aberdeenshire and Mearns county in Scotland, the tide flowing through the whole navigable length; it commences in the harbour of new Aberdeen,

where it is joined by the *Aberdeenshire* canal. New Aberdeen is the 19th town in Britain, with 17,597 inhabitants, and its harbour was improved by a pier of 300 yards in length, begun under the direction of Mr. John Smeaton, in 1770, who was employed again in 1778, to make farther improvements. In 1801, Mr. Thomas Telford was employed to design new works and improvements hereon, so that ships of 18 or 20 feet draught of water may be accommodated. There are excellent granite quarries near this river.

DEF RIVER, (Chester). The general course of this river is nearly S.E. for about 22 miles, in the county of Flint, and skirting the county of Chester: the first 9 miles are by a wide estuary opening to the Irish channel, and from near the town of Flint thereon, a new cut was made for the river up to Chester, under the direction of Mr. Nathaniel Kinderley, about the year 1749; before which time the old channel was so choked with sand, that ships of burthen could not come within 7 or 8 miles of Chester; the new straight cut, that was at first 8 feet deep in general, principally through marshes, soon scoured itself out, so that ships of 200 tons could come up to the town, and where the time of high-water became earlier by $\frac{3}{4}$ of an hour, than when the tide had to make its way through the old crooked and shallow channel. Chester is the 25th town, with 15,052 inhabitants, Holywell near it, is the 111th, with 5,567 persons, and Flint is also a considerable town. On the N.W. side of Chester the *Ellesmere* canal connects with this navigation and crosses it, for which goods pay 2d. per ton to this company; it is also to receive from the *Ellesmere* company whatever its tolls may fall short of 210l. annually. At Chester this river is joined by the *Chester* canal.

DEF RIVER, (Kirkcudbright). The course of this river is nearly N. for about 6 miles, in the county of Kirkcudbright in Scotland, being an estuary opening to the Irish sea. Kirkcudbright is a considerable town thereon, and where the *Glenkens* canal connects therewith.

DERBY CANAL. Act 33 Geo. III.—This canal runs nearly N. for about 9 miles, in the county of Derby; it is not greatly elevated above the level of the sea. Its objects are, the supply of the town of Derby, and the export of coals and iron. Derby is the 43d British town, with a population of 10,832 persons. It commences in the *Trent* river at Swarkstone bridge, crosses and intersects with the *Trent and Mersey* canal, and terminates at Little Eaton, near 4 miles above Derby, from which town a cut of $8\frac{1}{2}$ miles goes off to a place between Sandiacre and Long Eaton, and there joins the *Erewash* canal. There is a *rail-way* branch of $4\frac{1}{2}$ miles, to Smithy-houses near Derby, another to Horsley collieries, and another of $1\frac{1}{2}$ mile to Smalley mills. In case a *rail-way*, or canal, should be hereafter made S. of the *Trent* from Bredon lime-works, this company has engaged to make a cut between the *Trent and Mersey* canal and the *Trent*, at Welton cliff, opposite thereto. From the *Trent* to the *Trent and Mersey*, $\frac{1}{2}$ a mile, is a rise of — feet; thence to Derby, $5\frac{1}{2}$ miles, is a rise of 12 feet; and thence to Little Eaton, $3\frac{1}{2}$ miles, is a rise of 17 feet; the *Erewash* branch has a fall of 29 feet. This canal is 44 feet wide at top, 24 at bottom, and 5 feet deep, except the upper level next Little Eaton, which is made 6 feet deep to retain the water of wet seasons like a reservoir; the locks are 90 feet long, and 15 feet wide within side: adjoining the town of Derby is a prodigious large weir or tumbling bay, where the canal crosses the *Derwent* river, that was navigable to this place for many years back, but the tolls thereof were expected to fall off on the completion of this canal, and it was therefore agreed, that this company should purchase the whole concern for 3996l. A little W. of the river

above-mentioned, the canal crosses a brook in a *cast-iron* trough or aqueduct. This canal was finished in 1794; the company were authorized to borrow 90,000l. the value of shares being 100l. Separate rates of tonnage were fixed on different goods, between the *Trent* and the *Trent and Mersey*, between that and Derby, and on the different cuts and *rail-way* branches, which are too long for us to insert, they will be found in *Phillips' 4to. History of Canals, Appendix*, p. 55 to 59. Manures are to pass toll-free, and punchcons or clogs of wood, to be used as supports in the adjacent coal-mines, also road materials, except for turnpike-roads; and if the Mansfield turnpike-road tolls are reduced below 4 per cent. on their debt, this company is to make them up to that sum. The profits of this concern are not to exceed 8 per cent. but after 4000l. is accumulated as a stock for contingencies, the tolls are to be reduced. Five thousand tons of coals annually are to pass hereon toll-free, for the supply of the poor of the town of Derby. Horses pay 1d. and cattle $\frac{1}{2}$ d. each, for liberty of passing along each *rail-way* branch.

DERWENT RIVER, (Derby). The course of this river is nearly N.W. for about 9 or 10 miles, in the county of Derby; its principal object was the supply of Derby, previous to the making of the *Derby* canal, when this concern was sold to that company, as mentioned above. It commenced in the *Trent* river at Wilden-ferry, (where the *Trent and Mersey* canal commences,) and terminated at the town of Derby.

DERWENT RIVER, (New Malton). The general course of this river is nearly N. for about 37 miles, in the East Riding of Yorkshire; its objects are the supply of New Malton (a considerable town) with coals, deals, &c. and the export of farm produce, chalk, &c. It is but little elevated above the sea; it commences in the *Ouse* river at Barnby, and terminates at the town of New Malton. In January 1804, it was in contemplation to make this river navigable up to Yedingham bridge.

DERWENT RIVER, (Workington). The course of this river is nearly E. in Cumberland. Workington, on its banks, near the Irish sea, is the 109th British town, with 5,716 inhabitants; to the vicinity of this town there are several *rail-ways*, which bring down coals from Mr. Curwen's, and other coal-mines, for exportation from this place.

DEVON RIVER. The general direction of this river is nearly N.E. in Clackmannanshire in Scotland, from near Cambus quay, on the Frith of *Forth* (two and a half miles above Alloa) to Medlockfoot. Mr. John Smeaton was, in 1765, and again in 1768, consulted, about making this river navigable, or a canal by its side, the rise being $38\frac{1}{2}$ feet, in order to bring down the produce of several coal-mines near its banks, to be shipped on the *Forth*, wherein the spring tides rise 20 feet at Cambus quay. A branch was proposed to Alloa, and another to Sterling.

DEWSBURY AND BIRSTAL RAIL-WAY. The general direction of this *rail-way* is nearly N. for about 3 miles, in the West Riding of Yorkshire, and its object is to bring down coals to the vessels in the *Calder* river; it commences in the *Calder and Hebble* navigation at Dewsbury, and terminates at Stubley coal-mines in Birstal parish, which are worked by Messrs. Thomas Chester and Sons. who are also the sole proprietors of this iron *rail-way*, which was completed in the present month (October 1805).

DON, (or Dun) RIVER. Act 12 Geo. II. The general direction of this river is nearly S.W. for near 40 miles in the West Riding of Yorkshire, (including what is, in some maps, called the Dutch river, near to the *Ouse*,) the southern end of this navigation is rather elevated. The original objects

of this navigation were principally the supply of Sheffield, and the export of the iron-ware and iron from Sheffield, Rotherham, &c. since which period, the *Dearne and Dove* canal, which joins at Swinton, and the *Stainforth and Keadby*, at Fishlake and at Hangman Hill, and the cut to the *Ayre* river near Snaith, have opened new sources of supply, and for the export of coals, stones, iron, and manufactured goods of several kinds, which this rich track of country produces. Sheffield is the 14th British town, with 31,314 inhabitants; Doncaster is the 110th with 5697 persons; Rotherham, Doncaster, Thorne, and Snaith are also considerable towns on or near this navigation. The commencement is in the *Onfe* river, at Goole bridge, and it terminates at Attercliffe, within 2 miles of Sheffield, and has a cut to the *Ayre*, as above, and side-cuts with locks between Mexburgh and Swinton, and in other places; the tide flows above the junction of the river Went. The *Stainforth and Keadby*, act 33 Geo. III. has directed rates for boats passing out of this into that canal by the cut of this river. In September 1803, notices were given, for a new act for weirs and side-cuts to this river in Mexborough, Spotborough, and other places, and a new course for the river, near the junction of *Dearne* river. And, in February 1803, there was a design of extending this navigation to Sheffield by a canal from Tinsley, 4 miles, for which 30,000l. was subscribed.

DONNINGTON-WOOD CANAL. The general direction of this canal is about N. or N.E. for 7 miles in Shropshire; it is upon a very high level, nearly parallel to the grand ridge on the western side: its object is the conveyance of iron-stone and lime-stone, from the mines to the Donnington-wood iron works in Lileshal parish, and lime and coals for the supply of the town of Newport, which is a considerable place. It commences in the *Shropshire* canal (near its junction with *Shrewsbury* canal,) at Donnington wood, and terminates at Pave-lane wharf near Newport; it has a level branch to Lileshal lime-works, but on a higher level than the line, to which the lime-stone was formerly let down, in boxes through perpendicular shafts, at the same time that other empty boxes were ascending, the construction being nearly the same as the shafts afterwards used at Brierly-hill on the *Shropshire* canal, but like them they have since been disused and inclined planes are now used, on which boxes of lime-stone descend and draw up empty boxes by means of ropes passing over a large drum, to which a brake-wheel is adapted to regulate the motion. The boats hereon carry 25 tons of lading: the canal was cut in 1778 at the joint expence of the marquis of *Stafford* and Messrs. John and Thomas Gilberts. In June 1797 this was proposed to be joined at Pave-lane by the *Newport and Stour* canal.

DORSET AND SOMERSET CANAL. Acts 36 and 43 Geo. III.—The general direction of this canal is nearly S. for about 40 miles in the counties of Wilts, Somerset, and Dorset: the middle part of it is on a high level, and crosses the south western branch of the grand ridge. Its principal objects are the supply of the manufacturing towns and neighbourhood through which it passes, with coals from the mines bordering on Mendip, and the opening of an inland communication between the Bristol channel, the *Severn*, the *Thames*, and the southern coast of the island. Froome is the 60th town in the order of population, with 8,748 inhabitants, and Bradford, the 78th, with 7,302 persons; Bruton, Wincanton, Stalbridge, and Sturminster are also considerable towns near the line. The commencement is in the *Kennet and Avon* canal at Widbrook near Bradford, and the termination in the *Stour* river near Gains-crofts in Shillingstone-Okeford; from near Froome a branch of about 9 miles proceeds to Nettlebridge collieries in Midsummer-Norton.

The Nettlebridge branch was first cut, in order to supply coals to Froome and its neighbourhood; and water being scarce thereon, one of Mr. *Fuffel's* balance-locks was erected on a 21 feet fall at Mells near Froome, and was publicly tried on the 6th of September, and 13th of October 1800, and in June 1802, as particularly described in a previous part of this article. An aqueduct bridge was erected several years ago over the river near Froome, but it is with slow pace, we fear, that the works are proceeding towards a final completion. The company were by the first act authorized to raise 225,000l. and a further sum under the second, we believe, the amount of shares being 100l. Stones are to be erected at every half mile: pleasure-boats of 12 feet long and 5 broad may be used on the pounds, 30 yards in width are allowed, in general, for the company to purchase, and 100 yards wide for docks, wharfs, &c. springs may be taken and reservoirs formed any where within 2000 yards of this canal.

DOUGLAS RIVER (Lower Navigation.) Acts 6 Geo. I. and 10 and 23 Geo. III. (for *Leeds and Liverpool*). The course of this navigation is nearly south; for 9 miles in Lancashire it is but little elevated above the sea; its objects are the export of common and cannel coals, and farm produce, and the import of lime-stone; it commences in the tide-way in the estuary of the *Ribble* river near Insketh, and terminates in the *Leeds and Liverpool* canal at Brier's Mill. From the *Ribble* to Solom, about 5 miles, the river Douglas (or Afland) is navigable, and thence to Brier's Mill is a canal 4 miles, with a rise of 8 locks, the whole rise from the *Ribble* being 49 feet. The width of the canal is 24 to 30 feet, and depth of water 5 feet; the locks are 70 feet long, and 15½ feet wide. The first act above authorized Messrs. *William Squires* and *Thomas Steers* to make the *Douglas* river navigable from the *Ribble* to Miry-lane end, near Wigan, which they effected about the year 1727; being allowed 2s. 6d. per ton for goods, whatever distance they might be navigated thereon; by the first act for the *Leeds and Liverpool* canal (10 Geo. III.), their successors were authorized to make a junction with the *Leeds and Liverpool* canal at Newborough by a cut of 3¼ miles long, parallel to this river, with a fall of 13 feet, which they completed in 1774, and the same now forms part of the *Leeds and Liverpool* canal, S.E. of Newborough aqueduct bridge, in consequence of the purchase which that company made of the whole of this concern, in pursuance of their act of 23 of Geo. III.; since which, the canal from Brier's Mill to Solom above described, as part of the lower navigation, was cut and completed in 1781, and the river navigation between Solom and Wigan, 12 or 13 miles (on the upper navigation) has, we believe, been disused since the *Leeds and Liverpool* canal was completed by its side to Wigan, and the communication by the lower *Douglas* navigation to the *Ribble*, above described, was opened.

DOUGLEDGE RIVER. The course of this river is nearly north in the county of Pembroke in South Wales, from the tide-way in *Milford-Haven* to Haverfordwell bridge, its object being the supply of that town.

DRIFFIELD CANAL. Acts 7 and 41 of Geo. III. The course of this navigation is nearly north, for about 11 miles in the East Riding of Yorkshire; it is but little elevated above the sea; its general objects are the import of coals, deals, &c. and the export of farming produce; it commences at Aike-beck mouth in the *Hull* river, and terminates at the town of Great Driffield; the first five miles is by the course of the *Hull* river to Fish-holm clough, and the remaining 6 miles is by a canal; the course of the *Hull* river serves also as a branch of 1½ mile in length to Frodingham bridge. In 1764 Mr. *John Smeaton* was consulted on this intended navi-

gation. In 1804 it was in contemplation to deepen the Frodingham branch, and about 2 miles of the canal up to Snakeholme lock, nearly 2 feet deeper than it was before.

DROITWICH CANAL. Act 8 of Geo. III. The general direction of this canal is about N.E. for $5\frac{1}{2}$ miles in the county of Worcester; it is not greatly elevated above the sea; its objects are the export of salt and the import of coals, of which 13,500 tons are annually imported, and used in the boiling of salt, except what the town of Droitwich consumes. It commences in the river *Severn*, at Hawford, and terminates at Chapel bridge in the town of Droitwich; it has a rise of $59\frac{1}{2}$ feet by 8 locks. This canal was executed by Mr. *James Brindley*, and it is said to present a pattern to canal-makers by the neatness and regularity of its curves, and the stability and excellency of all its works. The proprietors were authorised to raise 33,400*l.* the amount of shares being 100*l.* The tonnage on every quarter of grain, or 6 bushels of meal, is 2*d.* and on every ton of salt, coals, or other matters, 1*s.* 6*d.* By the act for the *Worcester and Birmingham* canal (31 Geo. III.), the shares herein are guaranteed to produce 5 per cent. annually, and are to be made up by that company in case of their falling below that sum. Owing to the overflowings of the copious salt springs near Droitwich, this canal presents the curious spectacle of a salt-water canal, in the interior of the country, in which no river-fish can live.

DROMREAGH CANAL. This is a canal in Ireland, concerning which our information extends no further, than that the parliament of that country, between the years 1768 and 1771, granted 3000*l.* of the public money towards carrying on the works.

DRUMGLASS CANAL. This is a canal connecting with the Drumglass collieries in Ireland, towards the works of which canal, and those collieries, the parliament of that country, between the years 1753 and 1771, granted no less than 117,714*l.* of the public money!

DUDLEY (and Owen) CANAL. Acts 16, 25, 30, 33, and 36 of Geo. III. The general direction of this canal is nearly N.W. by a crooked course of 13 miles in Worcester-shire, a detached part of Shropshire, and Staffordshire; it is situate very high, its two ends are on the eastern side of the grand ridge, while its middle, by means of two very long tunnels, is on the western side of the same. Dudley is the 49th British town with a population of 10,107 persons, and the busy and rich country through which this canal passes, furnishes an ample tonnage in the export of coals, iron, and lime, while its communication with the *Stourbridge* canal, by the Black-Delph branch, and the terminating canals, occasions a very considerable carrying trade thereon. This canal commences in the *Worcester and Birmingham* canal at Selly Oak, and terminates in the old *Birmingham* canal at Tipton Green; from near Dudley there is a branch of 2 miles to the *Stourbridge* canal at Black-Delph in Kingwinford, there is another branch of $1\frac{1}{4}$ mile to near Dudley town, and a branch from this last of $\frac{3}{4}$ of a mile to Dudley coal-works. From the *Worcester and Birmingham* canal to the Black-Delph branch, $10\frac{1}{2}$ miles are level, thence to near the entrance of the Dudley tunnel, about $\frac{3}{4}$ of a mile is a rise of 31 feet by 5 locks, thence through the tunnel it is level, and from thence, in the last $\frac{1}{4}$ of a mile, is a fall of 13 feet by 2 locks, to the old *Birmingham* canal: the Black-Delph branch has a fall of 85 feet by 9 locks to the *Stourbridge* canal; the Dudley branch has a rise of 64 feet in the first $\frac{3}{4}$ of a mile, the remainder thereof being level, and the colliery branch level therewith. The depth of water in this canal is 5 feet; the width of the locks on the Black-Delph branch is 7 feet. To near Lapal, or Laplat, this canal passes through a tun-

nel 3776 yards long, at Gorfly hill it passes through another of 623 yards, under a collateral branch of the grand ridge, and at Dudley there is another tunnel of 2926 yards in length on the summit-level of the canal; the arch of this last tunnel has a height of $13\frac{1}{2}$ feet. At Cradley-pool is a large reservoir for supplying the lockage of the Black-Delph branch. It is provided, that level cuts may be made from this canal towards any coal-mine, to the extent of 2000 yards. A stop-lock is erected at the junction with the *Worcester and Birmingham* canal, by which either company has a power of preventing the other from drawing off their head of water. The Black-Delph branch was first executed, which was then united with the Dudley part of the canal which had been constructed by lord viscount Dudley and Ward; these were completed and in use before the extension or main length, to Selly Oak was designed. The company has been authorised to raise 229,100*l.* the amount of shares being 100*l.* each originally. Owing to the different acts under which the parts of this canal were progressively undertaken, the rates of tonnage being different thereon, and to the variety of rates on different articles, we cannot attempt an account thereof in this short abstract, they will be found in *Cary's Inland Navigation*, p. 53 to 55, also p. 43, where certain rates are made payable to the old *Birmingham* company on account of the junction therewith, (but which have since been varied by the 34 of Geo. III. for *Birmingham* canal) and at p. 70. will be found other rates, in consequence of the junction with the *Worcester and Birmingham* canal. In the *Stratford* act (33 Geo. III.) are several regulations relating to tolls on goods passing to or from this canal; and this company are bound to make up the profits of the *Stourbridge* canal to 12*l.* per share annually, but not exceeding 3*l.* on each share.

Durham and Chester-le-Street. In February 1797 Mr. *Robert Whitworth* made a report in favour of a proposed canal from the *Tyne* to Chester-le-Street, and thence to Durham, it was estimated to cost 79,000*l.* and the probable advantage thereon to subscribers was stated to be near 20 per cent. Durham is the 74th British town, with 7,530 inhabitants; this country abounds in coals.

EDEN RIVER. The general direction of this river is nearly S.E. for about 12 or 13 miles in the county of Cumberland; its principal objects seem the export of coals, and the supply of Carlisle, which is a considerable town. It commences in the tide-way of the *Solway* Firth, and terminates at Carlisle bridge. In 1795, the *Newcastle and Carlisle* canal was proposed to join this river at Carlisle. In 1799 a rail-way from the earl of Carlisle's coal-works, near Brompton, to this river, was opened; and in 1803 another was intended from lord Lowther's coal-works at Warnell, about 11 miles distant from Carlisle.

EDINBURGH AND GLASGOW CANAL. This canal, projected about the year 1796, appears to have nearly a west direction for about 50 miles in the counties of Edinburgh, Linlithgow, and Lanark in Scotland; its objects are the export of coals and lime from Clydesdale, through which it passes, and the opening of a direct communication between Edinburgh and Glasgow. Edinburgh (and Leith) being the 3d British town, with a population of 82,560 persons, and Glasgow the 5th, with 77,385 inhabitants; from the scanty materials to which we have at present access, it seems that this canal commences in the tide-way of the *Forth*, in the harbour of Leith, and terminates in the tide-way of the *Clyde*, in the town of Glasgow, and was finished in 1802; that at Glasgow it connects with the *Monkland*, and in 1803 the *Glasgow and Saltcoats* was proposed also to join it.

Eil and Shiel canal. In the year 1803 Mr. *Thomas Telford*

surveyed this line of canal, being a length of 3 miles from the tide-way in Loch Eil within some miles of the west end of the *Inverness and Fort-William*, or Caledonian canal, to Loch Shiel, a fresh-water lake on the Highland coast of Scotland; Loch Shiel was found $7\frac{1}{2}$ feet higher than Loch Eil, and in order to conduct a 12 feet deep canal out of the former to the shore of the latter, it appears that deep cutting will be required, for about a mile to the depth of $47\frac{1}{2}$ feet, there being no water on the summit to supply a lockage up and down.

ELLESMERE CANAL. Acts 33, two of the 36, 41, 42, and 44 of Geo. III.; the general direction of this canal is nearly south for 57 miles, by a crooked course through the counties of Chester, Flint, and Denbigh, (North Wales) and Salop; its principal summit is considerably elevated above the sea; its great object is said to be the improvement of the agriculture of the extensive and fertile tracts, through which it passes, for uniting the *Mersey*, *Dee*, and *Severn* rivers, and exporting coals, lime, and slate, from the skirts of the Welsh hills. Liverpool is the 4th British town, with a population of 77,653 persons, Chester is the 25th with 15,052 persons, Shrewsbury the 36th with 14,739 persons, and Ellesmere the 112th with 5,553 persons; Wrexham, Whitchurch, and Oswestry, are also considerable towns on or near this canal or its branches. This canal commences in the *Mersey* river (9 miles above Liverpool) at Ellesmere-port in Netherpool, and terminates in the *Severn* river at Bagley bridge, very near to the termination of the *Shrewsbury* canal, to which it is proposed to be joined; at the N.W. part of Chester city, it connects with the *Chester* canal, and near the same place crosses and connects with the tide-way in the *Dee* river; from near Pulford a branch of 4 miles is proposed to Holt; from near Gwerfelt a branch of — miles to Talwern coal-works in the parish of Mould, near the head of the Cegedog valley, where there is an opportunity of constructing a reservoir of 82 acres to supply the same (this branch to pass Frood collieries, Brumbo iron-works, and Nant-y-frith lime-works); another short cut from Gresford to Allington; and a *rail-way* branch to Ruabon-brook; and to the river *Dee* at Llandinillo; from near Pont-Cyfylyt, a branch to Acrefair coal-works; from Francton common, is a branch of about 25 miles passing the town of Whitchurch, to the *Chester* canal at Stoke in Acton parish near Nantwich; from which branch, another of about 7 miles proceeds from Pen-Mofs to Prees Heath; from Hordley on the main line, a branch of near 11 miles proceeds to the line of the *Montgomery* canal near Llanymynech, and the Verniew river; there being from this branch another to the termination of the *Montgomery* canal at Portyvain lime-works near Llanbyblodwell, and another short one is intended to Marda bridge near Oswestry. From the *Mersey* to the *Dee* (sometimes called the Wirral branch) the distance is 8 miles; from the *Dee* river to the Brumbo or Talwern branch it is $11\frac{1}{2}$ miles, with a rise of 380 feet; thence along the summit pond, and through the Chirk tunnel $8\frac{1}{2}$ miles are level; thence to the north end of the great iron-aqueduct, $\frac{1}{4}$ a mile, is a fall of 75 feet; thence to St. Martins moor, 9 miles, it is level; thence to the Whitchurch branch at Francton-common, $2\frac{1}{4}$ miles, is a fall of 13 feet; thence to the Llanymynech line at Hordley is $\frac{1}{4}$ of a mile with 33 feet fall; thence to Ormond park, $14\frac{1}{2}$ miles, is level; and thence to the *Severn* river at Shrewsbury is 2 miles with a fall of 107 feet. The Holt branch is level, the Whitchurch branch to that town, 14 miles, is level, and thence to the *Chester* canal, 11 miles, has a fall of 128 feet; the Prees Heath branch is level, the Llanymynech branch, 12 miles, has a fall of 19 feet. The depth of water in this canal is $4\frac{1}{2}$ feet, and the canal in general is calculated for boats of 70 feet long and 7 wide; but the Wirral branch is formed for boats of 70 feet long

and 14 feet wide. There is a tunnel near Chirk of 775 yards in length, and another at Weston-Lullingfield of 487 yards in length. At Pont-Cyfylyt, this canal is carried over the river *Dee* in an immense aqueduct trough, composed of cast-iron plates, 20 feet wide, 6 feet deep, and 320 feet long; this is supported on 19 pair of conical stone pillars at 52 feet asunder, and the middle ones 125 feet in height! at Chirk is a very large stone aqueduct bridge of 10 arches, 200 yards in length and 65 feet high, over the *Cerriog* river; and over the *Allen* river there is also an aqueduct bridge. This canal is fed from the *Dee* river by the Llandinillo branch, and that river is compensated by a cut from Bala-pool, and, all springs within 2 miles of this canal may be taken for its use. Near Ruabon, one of Rowland and Co.'s balance locks was, in 1797, tried on a 12 feet fall for saving water, as before mentioned. The engineers employed on this extensive work, were Messrs. William Jessop, Thomas Telford, — Fletcher, and Thomas Dadford; the most considerable progress was first made at the northern end of the line, and in February 1796, flats laden with coals began to arrive at Chester from the Lancashire collieries by the Wirral branch, and soon after convenient passage-boats were established, for the regular conveyance of passengers towards Liverpool or back, at lower rates than is charged on *Bridgewater's* canal, according to distance. In January 1797, the navigation was continued to Beeston brook; and in the same year the southern end of the line was opened from Shrewsbury to the Weston-Lullingfield tunnel. The immense aqueduct at Pont-Cyfylyt was in hand in 1804, and was more than half completed before the end of that year, as was also the stone aqueduct at Chirk. The company are authorized to raise 500,000*l.*, the amount of shares being 100*l.*, which it seems were, in 1802, at 20*l.* below par. The rates of tonnage are, for coals, culm, limestone, lime, and salt, 1*sd.* per ton per mile; for free-stone, timber, slate, iron-stone, lead ore, iron, and lead, 2*d.*, and for all other goods 3*d.* per ton per mile, except road materials and manures (but not lime) upon the pounds, or when the water flows waste over the lock-weirs. On crossing the *Dee* river at Chester, goods pay 2*d.* per ton to the *Dee* company, and their tolls are guaranteed to the amount of 210*l.* annually. While this canal was projecting, a rival scheme was started, called the Eastern Grand Trunk from the *Severn* at Shrewsbury to the *Chester* canal at Crow's nest, with cuts to Vable-Cruis, to Bonham-Furnace, Holt, and other places.

EREWASH CANAL. Act 17 Geo. III.—The general direction of this canal is nearly north for $11\frac{1}{2}$ miles along the skirt of the county of Derby, near to Nottinghamshire; its northern end is considerably elevated above the level of the sea; its chief object is the export of coals from the numerous collieries on its banks, and those on the banks of the *Nutbrook* canal which joins it at Stanton, and the *Nottingham* canal which joins it near Langley Bridge; the branch of the *Derby* canal joins it between Sandiacre and Long Eaton, and the *Trent* canal near Sawley. It commences in the *Trent* river near Sawley (opposite nearly to the *Loughborough* navigation, or Soar river,), and terminates in the *Cromford* canal at Langley Bridge, the rise being 1083 feet; there is an iron *rail-way* branch to Brinsley coal-works, on which an experiment was, as before related, made about the year 1800, on the load which one horse could draw both up and down the declivity. By the act of 33 of Geo. III. for *Derby* canal, a reduction of the rates between the junction therewith and the *Trent* river was made, conditionally, that no other junction be made between this canal and Derby, but the present one near Sandiacre; and by the 34 of Geo. III. for *Trent* river, the annual rent of 5*l.* is commuted for a toll of 6*d.* on every laden boat which shall cross the *Trent* between the

Soar river and this canal. A reservoir belonging to the Nottingham canal has a gauge-fluice, which furnishes a regular and daily supply of water to this canal. The first survey for this line of canal was made in the year 1776.

ESKE RIVER, (Montrose). This river is navigable but a short distance in the tide-way from the German Ocean to the town of Montrose, in Angus county in Scotland. Montrose is the 67th British town, with 7,974 inhabitants.

ESKE RIVER, (Whitby). The navigable part of this river is but short, in a S.W. direction in the East Riding of Yorkshire: it commences at the German Ocean, and extends to Whitby bridge. In 1765 Mr. John Smeaton was consulted about clearing this river and the harbour of Whitby, of the shail or refuse ore, from which alum had been manufactured, and whereby the harbour had become in time nearly choaked up. Whitby is the 75th British town, with a population of 7,483 persons; within a few years past, a pier has been built with free stone, under the direction of Mr. John Rennie, for the improvement of the mouth of this harbour.

EXE RIVER. The course of this river is nearly N.W. for about 10 miles in the county of Devon; its principal object seems the supply of Exeter and Topsham; near Topsham it is to be joined by the *Grand Western* canal. It commences in the English Channel at Exmouth, and terminates at the city of Exeter, which is the 21st town in Britain, with 17,398 inhabitants: from Exeter it was in 1800 proposed to continue the navigation to Crediton; and in 1769, the *Exeter and Uphill* canal was proposed to be made from the same place.

Exeter and Crediton. In the year 1800 it was proposed to make the rivers Exe and Credy navigable, from Exeter city to the town of Crediton, about seven miles, above Exeter quay on the river Exe.

Exeter and Uphill. In 1769 Mr. John Brindley surveyed the country for a canal from the river Exe at Exeter, by Tiverton, Wellington, Taunton, and Glattonbury, to the British Channel near Uphill; the objects of which have been since embraced in the *Grand Western* canal.

FERGUS CANAL. This is one of the Irish inland navigations, in aid of which, public money was from time to time granted, though in the present instance we are told that it amounted to no more than 85l.

FORTH RIVER, (or Forth). This principal river of North Britain has its course nearly west for about 70 miles between the counties of Fife, Haddington, Edinburgh, Linlithgow, Stirling, Perth, and Clackmannan; the first 33 miles being a very wide estuary, the next 18 miles are still of considerable width, and the last 13 miles next Stirling are remarkably crooked. An immense general trade is carried on upon this river, and for the supply of the metropolis of Scotland, assisted by the *Edinburgh and Glasgow* canal, that joins it at Leith, the *Burrowslowness* at that town, the *Forth and Clyde*, or great canal at Grangemouth, the *Caron* river near Rothkennar, and the *Devon* river near Cambus Quay. Edinburgh (with Leith) is the 3d British town, with 82,560 inhabitants, Dumfries is the 52d, with 9,980 persons, and North Berwick, Crail, Anstruther, Dysart, Kirkaldie, Kinghorn, Bruntisland, Inverkeithing, Musselburgh, Queen's-Ferry, Burrowslowness, Linlithgow, Falkirk, Culros, Clackmannan, Alloa, and Stirling, are also considerable towns on or near this fine river. It commences in the German Ocean, and terminates at Stirling bridge, and is navigable for ships through a great part of its course; at Cambus Quay the spring tides rise 20 feet, but below this there are lands called the Thrask Shallows, concerning the removal of which, Mr. John Smeaton was consulted in 1767. In 1801, the channel south of Inch-keith was

deepened, to enable ships to approach Leith harbour more safely and readily. Leith harbour has undergone great improvements of late years under the acts of the 28, 38, 39, and 45 of Geo. III., by the last 25,000l. of the public money was granted for the wet-docks and other works which have been carrying on there under Mr. John Rennie, since the laying of the foundations, 14 May 1801. Methel harbour on the north side of the *Forth* is also under improvement, and by the 45 of Geo. III., 2,000l. of the public money was granted towards the building of the pier there. In the year 1767, Messrs. Watt and Morison surveyed the upper part of the *Forth* river, and proposed to extend a navigation from Sterling bridge to the slate and lime quarries in Aberfoil, on which the opinion of Mr. John Smeaton was also taken.

FORTH AND CLYDE CANAL. Acts 8, 13, and 24 of Geo. III.—The general direction of this great canal is nearly west for 35 miles, in the counties of Stirling, Dumbarton, and Lanerk, in Scotland: it crosses a low part of the grand-ridge between the tide-ways of the east and west seas; its principal object is a communication between those important rivers, the *Forth* and the *Clyde*, and between the northern metropolis, and the great manufacturing towns of Glasgow, Paisley, &c.; near to Grangemouth the *Burrowslowness* canal joins it. Glasgow is the 5th British town, with a population of 77,385 persons, and Falkirk the 59th, with 9,838 inhabitants. Kirkintulloch and Dumbarton are also considerable places near the line. This canal commences at Grangemouth harbour in the *Forth* river, and terminates at Bowlings bay near Dalmuir-Burnfoot, in the *Clyde* river. There is a cut of 2½ miles to the town of Glasgow, where it joins the *Clyde* river, the *Munkland* canal, and the *Edinburgh and Glasgow* canal; and it was in 1803, proposed to join the *Glasgow and Saltcoats* canal; there is another cut with a lock into the *Caron* river at Caron-shore, near the great Caron iron-works. From low-water in the *Forth* in Grangemouth lock, N^o 1, to lock N^o 20, 10¼ miles, is a rise of 165 feet; thence to lock N^o 21, the summit-level is 16 miles, and thence to low water in the *Clyde* at Bowlings bay lock, N^o 39, is a fall of 156 feet; the width of the canal is 56 feet at top, and 27 at bottom, and the depth of water 8 feet; each lock is 75 feet long, and 20 feet wide in the clear, and vessels of 70 or 80 tons are used. This canal is crossed in 33 places by draw-bridges, has 33 culverts or arches under it, and 10 large aqueduct bridges; that over the Kelvin is 400 feet in length, and 70 feet high above the surface of the river, (see figs. 19, 20, and 21, *Canals*, Plate II.) and there is a large aqueduct which crosses the turnpike road from Glasgow to Stirling at Kirkintulloch. At Kilmananmuir is a reservoir of 70 acres extent, and 22 feet deep at the sluice; and near Kilsyth is another of 50 acres, 24 feet deep for supplying the summit-level of this canal. In Bowlings-bay, and near the Kelvin aqueduct, are dry-docks, and other conveniences for repairing of vessels and boats. Mr. John Smeaton was first employed to survey this line in 1764, and he laid the present design, and executed a considerable part of the eastern end before 1775, when the work stood still for some years, after which, Mr. Robert Whitworth was called in; he completed the remainder, and it was opened with great solemnity on the 28th of July 1790. The design of a canal between the *Forth* and *Clyde* has been at times entertained ever since the reign of Charles II., and besides the above engineers, since the year 1723, Messrs. Gordon, Mackell, Watt, Brindley, Golborne, Thomas Teoman, &c. have been consulted or employed. The canal was first made to commence in the *Caron* river, about a mile from its mouth, but was afterwards continued into the *Forth* at Grange-

mouth harbour. The proprietors were authorised in their first act to raise 200,000*l.* in 100*l.* shares; after which, 50,000*l.* of the public money was granted to aid the work; in 1783, 212,000*l.* had been expended, and no dividend or interest had been paid on the shares. The rate of tonnage is 2*d.* per ton per mile on all kinds of goods, except lime and lime-stone, which is to pay ½*d.*, and iron and iron-stone 1*d.* per ton per mile, while road-materials (except lime-stone) and manures are to pass toll free. For unloading or loading of British or Irish vessels in Grangemouth harbour, 1*d.* per ton is to be paid, (by 24 Geo. III.) and for foreign vessels 2*d.* per ton. Rafts of fir timber are allowed to be floated upon this canal and pass the locks, these often contain 70 tons each. An accident is related of a vessel coming down from the westward on this canal, when the wind blew strong from that quarter, and not being stopped in time at one of the locks, she bore down the gates, and went down suddenly into the pond below. In December 1801, a vessel constructed by Mr. Symington, (as already described) was tried on this canal for dragging or towing boats, by the operation of a steam-engine; to the head of this vessel stampers were applied, that could be worked by the engine for breaking ice, when the canal is frozen over.

FOSS-DYKE CANAL. The general direction of this navigation is nearly S.E. for 11 miles, in the counties of Lincoln and Nottingham; it is upon one level, not much elevated above the sea, though a great distance from it, and presents the curious instance of a canal discharging its waste water into one river (the *Witham*), while flood-gates are necessary at the other end, to keep out the waters of the other river (the *Trent*); its object is a communication between these two rivers, for supplying coals and exporting farm produce. Lincoln is the 76th British town, with a population of 7,398 persons. This canal commences in the *Trent* river at Torksey, and terminates in Brayford meer, a natural pool in the *Witham* river, near Lincoln. It has a lock at Torksey, constructed on the principle of a sea-lock, that is capable of penning the water into the canal, or out of it, according to the circumstance whether the *Trent* or it may be the lowest; between Brayford meer and Lincoln high-bridge, a hard of gravel or shallow, called Brayford head, held up the water in this canal, to about 2½ feet deep, which otherwise would, in dry times, have been emptied into the *Witham*, too low for navigation. Mr. John Smeaton and Mr. John Grundy were consulted in 1762, and the former engineer again in 1782, when he recommended raising the banks of this canal to obtain a better depth of water, cutting off its connection with the *Witham* by a pound-lock, and supplying it with water by an aqueduct or feeder, from a reservoir to be made near the *Witham*, south of Brayford meer. We are not acquainted with the date when this canal was first dug or made navigable; Mr. Ellison's wharf thereon, near its east end, was, it appears, built about 1742.

FOSS NAVIGATION. Acts 33 and 41 Geo. III.—The direction of the *Foss* river, which this navigation follows, is nearly N. by a crooked course of about 13 miles, through the North Riding of Yorkshire: its elevation is not very great above the level of the sea; its objects are the supply of the city of York, the import of coals for the use of the adjacent country, and to effect a better drainage of the same. York is the 23d British town, with 16,145 inhabitants. This navigation commences in the *Ouse* river at the city of York, and terminates at Stillington mill. It is fed by a reservoir on Ouslone moor: it appears that the corporation of York were by a licence of king Richard II. required to erect and maintain proper bridges over this river. This company were authorised to raise 45,400*l.* the amount of

shares being 100*l.* each. The rates of tonnage will be found in *Phillips's 4to. History, Appendix*, p. 81 and 82; and in the last act, by which an additional 1½*d.* per ton, on heavy articles, were imposed, and by which the proprietors were authorised to proceed no higher than Sheriff-Hutton bridge with their works, until the necessary funds were accumulated to proceed with the remainder of their line. Some years ago, a pleasure-boat, made wholly of sheet iron, was tried on this navigation, 12 feet long, and capable of carrying 15 persons, and yet so light that two men could carry it.

GLAMORGANSHIRE CANAL. Acts 30 and 36 Geo. III.—The general direction of this canal is nearly N.W. for 2½ miles, in the county of Glamorgan in South Wales. Its objects are the export of the produce of the immense iron, coal, and lime works in the neighbourhood of Merthyr 'Tidvil, &c. and the supply of the rapidly increasing population thereof; at Eglwylfa the *Aberdare* canal joins, and the *Cardiff and Merthyr* rail-way runs by its side, and joins it at those two places. Its northern end is considerably elevated. Cardiff and Caerphilly are considerable towns on or near the line; it commences in a sea-basin, or dock, in the *Severn*, at the Lower-layer near Cardiff, and terminates near the town of Merthyr; it has a rail-way branch from Merthyr to Dolau iron works. From the tide-way at Lower layer to Merthyr is a rise of near 600 feet, and during a part of this distance the canal skirts precipitous mountains at the height of near 300 feet above the river Taw or Taaff, which it closely accompanies through its whole length. The floating dock at Lower-layer is 16 feet deep, in which a great number of ships, of 300 tons burthen, can lie constantly afloat, and load or unload, either at the spacious warehouses on its banks, or from, or to, the boats belonging to this canal, or the trams used on the *Cardiff and Merthyr* rail-way, that here commences. There is a large aqueduct bridge over the Taw near Gallygare. This company were authorised to raise 100,000*l.* and to the powers for raising the last 10,000*l.* this singular condition was annexed, viz. that the whole concern should be completed within two years, after which no further money should be applied, except for repairs. At Merthyr there is a famous water-wheel, made of cast-iron, 50 feet diameter, at Mr. Crawshaw's works; the water being conveyed thereto for a great distance in an iron aqueduct.

Glasgow and Saltcoats. In May 1803 the line of country between the *Clyde* river at Ardrossan, near Saltcoats, and the *Clyde* river again at Glasgow (passing Paisley and connecting with the *Canal* river) was surveyed by Mr. John Rennie; in 1805, the subject was revived, and met the support of the earl of Eglintown and many others, coupled with the design of building a pier on a ledge of rocks near Castle Craigs, and forming wet-docks, &c. to be called Ardrossan harbour, for which an application was made to parliament in the same year. At Glasgow this canal would connect with the *Forth and Clyde*, the *Monkland*, and the *Edinburgh and Glasgow*: the line thereof is through a country rich in coals and lime-stone.

GLENKENNS CANAL. Act 42 Geo. III.—The direction of this canal is first N.E. and then N.W. for about 27 miles, in Glenkens, in the county of Kirkcudbright in Scotland: it is not very greatly elevated; the object of it is the export of the coals, iron-stone, lime, and other minerals with which the country abounds; Kirkcudbright and New Galloway are considerable towns near the line. It commences in the tide-way in the *Dee* river at Kirkcudbright, and terminates in the boat-pool at Dalry. There is provision made for branches to the neighbouring mines and rail-ways, and inclined planes may be substituted, instead of a canal and locks in any part. The company is authorised to

raise 45,000*l.* the shares being 100*l.* each. but it is provided, that the works are not to commence until 20,000*l.* is subscribed, and that within five years, or the powers of the act are to cease; water may be taken from within 2000 yards of the line, except certain streams used for irrigation.

GLOUCESTER AND BERKLEY CANAL. Acts 33, 37, and 45 Geo. III.—The general direction of this canal, one of the largest in England, is nearly N.E. for 18½ miles, in the county of Gloucester; it is but very little elevated above the sea; its object is to shorten the navigation for ships by a serpentine course of 28 miles on the *Severn* river, between Berkley and Gloucester; near Wheatenhurst it crosses and unites with the *Stroudwater* canal; Gloucester is the 72d British town, with a population of 7,579 persons; Berkley is also a considerable place. This canal commences with a sea-lock in the *Severn* river at Berkley-pill, and terminates in a grand and capacious basin, connecting with the *Severn* river at Gloucester, it has a short branch to a new wharf at Berkley town, and another of about 2 miles in length to the *Severn* river at Hock-crib in Arlingham; the whole is on one level with tide-locks at its connecting points with the *Severn* to preserve its water at one constant height. This canal is 70 feet wide, and 15 or 18 feet deep in water, and the locks, &c. thereon, are capacious enough to admit ships of 300 tons burthen to pass! The company are authorized to raised 200,000*l.* in 100*l.* shares. The tonnage varies on different sized vessels, and is too long for us to insert, the particulars will be found in *Phillips' 4to. History, Appendix*, p. 83 and 84. Unforeseen difficulties have attended the execution of this wide and deep canal, by intersecting a hard rock for great distances in the level meadows, where no such thing was expected. Some immensely large slips have happened in the banks, and the walls of the Gloucester basin slipped in, notwithstanding the land-ties which had been provided; the upper end of the canal, for several miles, has been finished; in 1797, it was said that only 6 miles remained to be cut; and we hope, that the act of last sessions will be the means of speedily completing the whole. Mr *Hafkew's* machine, calculated to assist in excavating a canal, was here tried in 1796, as before mentioned.

Gloucestershire Rail-way. In the year 1804 it was proposed to construct a rail-way from the *Avon* river at Bitton below Bath to Sodbury coal-works in Gloucestershire, with branches to Pucklechurch, Haul-lane, Coal-pit-heath in Westerleigh, Smith's tydings, and other collieries, in order to bring their produce to Bath and Bristol, and for the consumption of the interior of the country, by means of the *Kennet and Avon* canal.

GRAND CANAL, (Ireland). This canal was commenced, we believe, soon after the year 1753, but we have not the dates of the earlier acts; since the union there was one passed, the 43 Geo. III. The general direction of this canal is nearly west, for 61½ miles through Dublin, Kildare, and King's Counties, in Ireland; it passes a low part of the grand ridge of Ireland, on the Bog of Allen. Its objects are the supply of Dublin with coal, &c., the varied produce of the banks of the *Shannon*, and opening an inland communication through the country. It commences in a grand basin in James-street, Dublin (which connects with the *Liffey* river and the new *Docks*), and terminates in the *Shannon* river, at Tarmonbarry, near Moy's Town; it has collateral branches to the *Boyne* river at Edenderry, to the *Darrow* river at Monefraven, and also at Portarlinton; there are also branches to Naaltown and to Johnstown. This canal is, we believe, 5 feet deep, the locks are 80 feet long and 16 wide, in the clear, and are built of hewn stone; it has employed the attention of various engineers, among whom are mentioned, Messrs. *Omes, Vallency, John Traill,*

William Jessop, &c. In the year 1770 this canal had proceeded from Dublin into the Bog of Allen, when, owing to mismanagement, it stood still for several years, and it was not until the beginning of 1804 that the whole line was finished and opened. The sums of the public money which have been granted by the parliaments to aid this work are immense; between 1753 and 1771 they amounted to 78,231*l.* It has been proposed to reduce the tolls or tonnage since the opening of this canal. In the beginning of the present year (1805) it was proposed to continue a branch from this canal, near Athy, for 9 miles, to the foot of the Doonane Hills, in Queen's county, and thence to tunnel two miles into the hill, to drain the rich veins of coal therein, and bring out their produce.

GRAND JUNCTION CANAL. Acts 33, 34, three of the 35, 36, 38, 41, 43, and two of the 45 Geo. III.—The general direction of this canal is nearly north-west for 90½ miles, in the counties of Middlesex, Hertford, Buckingham, Bedford (a very small distance), and Northampton. It has a summit of considerable height near Tring, which it passes without a tunnel; and near its northern end it crosses the grand-ridge by a tunnel. Its principal objects are, a communication between the metropolis and the various canals of the midland counties, the supply of coals, deals, slate, &c. to the several towns on the line and branches, and the export of the agricultural products, lime, flints, &c. of the country through which it passes; at Northampton it joins the *Nen* river by a rail-way branch, and the same is intended there also to join the *Leicestershire and Northamptonshire Union* canal. London, as is well known, is the first town in Britain for population, with 804,845 inhabitants, and Northampton is the 85th, with 7,020 persons; Brentford, Uxbridge, Rickmansworth, Watford, St. Albans, Hemel-Hempstead, Berkhamstead, Tring, Wendover, Aylesbury, Leighton-Buzard, Fenny-Stratford, Newport-Pagnel, Stoney-Stratford, Buckingham, Towcester, and Daventry, are also considerable towns on or near this canal or its branches. The commencement of this canal is in the river *Thames*, near the extremity of the tide-way at Brentford creek, and its termination in the *Oxford* canal at Braunton. From Bull bridge a branch, 13½ miles in length, goes to Paddington, one of the environs of London; to the town of Rickmansworth, there is a cut of about ¼ of a mile, with a lock at its entrance; from Bulbourn head a branch extends for 6¾ miles to Wendover; from Cosgrove a branch of 1¼ mile extends to Stoney or Old Stratford, and thence 9½ miles further to Buckingham; and from Gayton a rail-way branch of 5 miles extends to the river *Nen*, and the intended termination of the *Leicestershire and Northamptonshire Union* canal at Northampton. To Watford a branch of 2 miles, and thence about 8 miles farther to St. Albans, has been surveyed and provided for in the acts; another to Aylesbury of about 6 miles, and another to Daventry of 1½ mile in length, but these last are not executed. From the *Thames* at Brentford to Two-waters is 28½ miles, with 268 feet rise; thence to Cowroast is 7¼ miles, with a rise of 127 feet; thence to the Wendover branch is 3¼ miles, of the highest summit-level; thence to the crossing of the Ouse river, between Wolverton and Cosgrove, is 25¼ miles, with a fall of 192 feet (this being the lowest place); thence to Stoke Bruern is 6¼ miles, with a rise of 112 feet; thence (through the Blisworth tunnel) to the south end of Whitton parish, 13½ miles, is level; thence to Whitton mill, in Long Buckby, ¾ of a mile, is a rise of 60 feet; thence along the summit-level, and through Braunton tunnel to its north end, 4¼ miles, is level; and thence to the *Oxford* canal at Braunton, near 1 mile, is a fall of 37 feet. The Paddington branch is level (at about 50 feet above the *Thames*, and 48½ feet above the Strand-pavement at Exeter-

change). The Wendover branch is level, and connects with the Bulborne or Tring summit pound: the Buckingham branch has a rise of 15 feet; the Northampton branch has a fall of 120 feet, and the cut to Daventry is to have a rise of 60 feet. The width of the main line is 36 feet at top, about 24 feet at bottom, and $4\frac{1}{2}$ feet deep in water: the Wendover branch is 28 feet wide at top, 18 at bottom, and $4\frac{1}{2}$ feet deep; and the Buckingham branch is only 20 feet wide at top, 10 at bottom, and $4\frac{1}{2}$ feet deep in the general. The Northampton rail-way, which is now (October 1805) nearly or quite finished and ready for opening, is of iron, and double, that is, has two roads for the carriages going different ways. The locks on the line are 86 feet long, 15 feet wide in the clear, and rise about 7 feet each on the average, requiring about 9030 cubic feet, or 250 tons of water to fill them each time that a barge passes. On the line there are 101 locks, besides the 9 spare ones in Wolverton-valley; on the Buckingham branch there are 2 locks. Two kinds of vessels are in use upon this canal, barges with square heads and sterns, and flat bottoms, that carry 60 tons, and boats with sharp ends, or nearly so, of half the width, that carry 25 tons. At White-friars, just above Black-friars-bridge, on the *Thames*, this company built extensive warehouses, over a dock, in which barges lay afloat from one tide to the next; these are now let to Mr. *Pickford*, the great waggon and boat-master. At Paddington a spacious basin or straight cut, 400 yards long and 30 wide, has been formed with wharfs at its head, and others are daily extending wellward along its sides; behind this, on the north side, is a spacious yard for a vegetable and a hay and straw market, with immense sheds, under which loads of those articles can stand in the dry when it rains; and on the south side pens are erected and provision made for a large cattle market. The number of wharfs erected on this extensive line and its branches by individuals are too great for us to attempt to particularize them. The number of culverts or small water-courses under the canal and its branches are very great. And on the towing path there are a number of large and high wooden bridges for crossing the entrances to branches, docks, or over streams of water; for some distance from Paddington provision is made under the bridges for a towing path on each side of the canal. The tunnel between Stoke-Briern and Blisworth (already described), is 3080 yards in length, 15 feet wide, and 19 feet high, at 60 feet below the top of Blisworth hill, through which it penetrates. Braunston tunnel, between that place and Daventry, is 2045 yards in length: another tunnel was at first intended near King's-Langley for avoiding Cashbury, and other parks in the Colne valley; but an agreement was afterwards come to with their owners for a passage through them, instead of tunnelling. Between Cow-roast and Bulbourne there is an immense deep-cutting for passing the great range of chalk-hills near Tring; this extends for 3 miles, and is 30 feet deep in the highest part; near Dawley there is a great length of deep-cutting through the immense bed of gravel at that place; at the ends of the Blisworth tunnel, and at several other places there are also deep-cuttings. Between Wolverton and Cosgrove a stupendous embankment, with three aqueduct arches under the same, has been constructed, since the locks were made for crossing the Ouse river, as above mentioned, over which the canal has, since August 1805, been conducted, and by which 4 locks on the south side of the valley, and 5 locks on its north side, are avoided, except a lock of 18 inches rise, near the north end of the embankment, by which 12 miles in length of level pound is held up (on the line and Buckingham branch), and separated from 10 miles of level pound south thereof, to beyond Fenny-Stratford town, (where another lock of only 18

inches rise occurs, to hold up a pound of some miles in length that was intended, but for a mistake in the levelling, to have been in one pound); this embankment is $\frac{1}{2}$ a mile long, and 30 feet high, where it crosses the Ouse. At Weedon-Beck, and at Bugbrook, there are also most stupendous embankments, and river and road aqueduct-arches, and many lesser embankments and aqueduct bridges occur on the line and branches; those over the Brent river, and over Bays-water on the Paddington branch are considerable. On Harefield Moor there is a very wide and large piece of water on the canal: others at Great Berkhamstead, at Halton park, and two other places on the Wendover branch. Five considerable reservoirs have been constructed for preserving water for this canal, or for the mills, whose streams have been diverted for its use; that at Aldenham covers 68 $\frac{1}{2}$ acres, at Willstone is one of 40 acres, and those at Weston-Turville, Braunston, and Daventry, are also of very considerable dimensions. The principal feeder for the southern summit is at Wendover, and there are others at Little Tring, Tring, and Mifwell (the last being arched over for $\frac{1}{4}$ of a mile). The middle and lower part of the line is supplied by a feeder at Soulbury, and the northern summit is supplied by a feeder from Watford, near Daventry; besides which, that summit has had its banks raised to accumulate an extra depth of water in wet times, and a steam engine has recently been erected for pumping up the water out of the level of the *Oxford* canal to that summit, that is let down therefrom by the lockage. At Little Tring an engine was, in June 1803, erected for pumping the water collected in Willstone reservoir into the Wendover branch of the southern summit-level; and at Nash mill, some distance below Two-waters, in the Colne valley, an engine is now erecting to return the lockage water of 4 locks that are there placed near to each other. On the south and north sides of the Tring summit, several pairs of side ponds have been lately added to the locks, for saving part of their consumption of water. Where the Towcester river (the Tove) is crossed and joined there are very considerable weirs or tumbling-bays, and others on the old course, in the Wolverton valley; and, between Great Berkhamstead and Uxbridge, these are continually occurring, owing to the canal having unfortunately been conducted into and through almost every mill-dam in that distance: overfalls of less size are also very common on every part of the line, so are stop-gates, trunks, and every other necessary appendage and convenience to a navigable canal. Mr. *William Jessop* was the engineer to this extensive concern; Mr. *James Barnes* and Mr. *John Holland* were employed in executing different parts of the works, on which Mr. *Thomas Telford* was lately employed to report his opinion; since 1803 Mr. *Benjamin Bevan* has been employed in repairing the leaky parts, constructing side-ponds, &c. in the middle district of this canal. The works on this canal commenced at both of its extremities, soon after the passing of the first act; and the tunnel at Braunston being completed, the navigation was opened, in July 1796, as far southward from the *Oxford* canal, as the great embankment at Weedon Beck; in June 1797, the same was extended to the next great embankment at Bugbrook; and about November in the same year, to the north end of the intended tunnel at Blisworth. Beginning at the southern end in the *Thames*, the navigation to Two-waters was completed in June 1798, and in June 1801 the branch therefrom to Paddington was opened; in the year 1799, the canal was completed to Bulbourne, and the branch therefrom to Wendover; in June 1800, it was extended to Fenny-Stratford; and about October 1800 to the south end of the intended tunnel at Blisworth; at the same time a double iron rail-way of near 34 miles in length (since removed) was laid across Blisworth

Hill, to connect the two parts of the canal, and form the much wished for grand junction; in May 1801, the branch to Buckingham was opened; it was not until March 1805 that the Blisworth tunnel was completed, and the navigation of the whole line opened; and, lastly, in August 1805, the immense Wolverton embankment was opened for improving the same, and avoiding 8 locks, but which locks still remain by its side, as a reserve, in case of accident, to this immense mound of earth, or the three large arches under it. This company were authorised by their first nine acts to raise 1,528,000*l.* to which their first act of last session made a considerable addition; and it is feared that the expenditure will altogether exceed two millions sterling! The shares are of 100*l.* value each, which have at some periods of the business sold as high as 210*l.*, and at others have been down at 65*l.*! Shares in this concern are allowed to be split into such small portions among different holders, as $\frac{1}{4}$ th or $\frac{1}{12}$ th each. On the original shares no dividend or interest has yet been received, but now as the tolls amount to full 7,000*l.* per month, it is hoped a dividend will begin to be made. Inland coals from the rich and inexhaustible mines with which this and other canals form direct communications, were forbid under severe penalties (although two legislative attempts to enforce the same proved inefficient) to be brought nearer to London than the N.W. end of Grove park in Hertfordshire, until the last act of the late session mentioned above, by which 30,000 tons of such coals are allowed to be brought to Paddington in the current year, on paying a duty equivalent to that paid in the *Thames* on sea-brought coals. The market at Paddington, after an ineffectual and most extraordinary opposition from the city of London, was opened in May 1802, for the sale of fat cattle, hay, straw, corn, vegetables, &c. By the act 41 Geo. III., this company was authorised to lay pipes in certain streets in Paddington, Marylebone, &c. for supplying the inhabitants with water; but at that time, certain millers, whose dams the line had been made to pass through, were not consulted. In June 1801, packet-boats were established, that continue to pass regularly at stated hours during most of the year, for the conveyance of passengers and parcels between London and Uxbridge; and for some time after the opening of the Buckingham branch, a boat went regularly between Paddington and that town; but the number of passengers and parcels were found inadequate to support the expence of such an establishment. Trading boats are not allowed to pass along upon this canal except in the day time, unless such as have a special licence from the company for such purpose. Mr. Pielford has a great number of boats, which proceed as regularly day and night upon this canal, and the other canals north of it, as the mail-coaches do on the roads, although with less expedition. A common trading boat has been known to arrive at Paddington in 63 hours from Coventry. In December 1799, the experiment was first tried, of bringing fat Oxen to London in boats by means of this canal. The rates of *tonnage* on this canal were at first very low, as will be seen in *Phillips' 4to. History, Appendix, p. 91.* Additional tolls were provided in the 43d of Geo. III. for passing the Blisworth tunnel and Wolverton embankment; and by the first act of the last sessions (45 Geo. III.), the rates on the whole line and branches were varied, and increased for short distances. The act of the 33d provided certain rates, which are to be paid to the *Oxford* company (See *Phillips' Appendix, p. 93.*) for goods passing thereon to or from this canal, and this company is bound (since the beginning of 1804), to make up the same to the amount of 10,000*l.* per annum. This company is

also bound to pay annually to the city of London the sum of 600*l.* for the liberty of making a junction with the *Thames*; and all goods passing into or out of the same on this canal are to pay 4*d.* per ton, to be applied towards improving the middle navigation of the *Thames* river. The intended cut to Aylesbury was, on account of the scarcity of water at Marlow, where it was to join the line, changed for a rail-way, and in the year 1803, the same was begun; the iron rails were actually purchased, and brought to the spot, but, alas! in one of those reverses of favour to which borough towns are ever liable, the work was stopped, the rails were ordered to be sold, and years may now perhaps elapse before Aylesbury is permitted to enjoy the advantage of a canal or rail-way communication. About the year 1793, an extension of the Rickmanworth branch of this canal was proposed to the town of Chessham. In 1793, and again in 1802, it was proposed to extend a branch from near Slapton to the foot of Puddle-hill between Dunstable and Hockliff; one object of which was the export of the valuable white freestone from the quarries at Tottenhoe; this object may, however, it is presumed, be obtained without such cut; and stone of equal quality be got in several places on the summit branch. In the year 1802, the country westward of Uxbridge was surveyed by Mr. John Holland, with the intention of extending a branch of this canal from below Cowley lock, (continuing the level of the Paddington water) to the *Thames* at Harleford in Great Marlow parish; it was also proposed, after crossing and uniting with the *Thames* at this place, to extend this branch, by a rise of three locks, to a side-cut of the *Kennet* river at St. Giles's in Reading, with a branch therefrom to the *Thames* at Sunning; the objects of this branch were, a more direct communication with the Bristol channel, by means of the *Kennet* and *Avon* canal, the supply of the country bordering on this canal and its branches with peat manure from near Reading, the better supply of, and communication with London, by means of a canal without a lock, between the *Thames* at Great-Marlow, and Paddington, the gaining from the *Thames* that supply of water, which had been denied from the Colne for the intended water-works, and the lockage of the *London* canal; which was, in 1802, proposed to extend from the basin of this canal at Paddington to the *London Docks*, and thereby to communicate with the *Thames*; after which a rail-way was, in the same year, proposed to extend from Paddington over nearly the same ground. It was before 1773 that a canal was first proposed from Paddington to Uxbridge, nearly in the route of the line now accomplished; and in 1773, Mr. James Sharp proposed an extension of this to the *Kennet* river. In June 1803, a survey was taken for extending the intended Aylesbury branch by Tame to the *Thames* and *Isis* navigation, and *Wills and Barks* canal near Abingdon. And in the same year, the *Leicestershire and Northamptonshire Union* canal was proposed to be joined to the line of this canal at Long-Buckby wharf near Daventry, instead of joining its Northampton branch at that town.

GRAND SURRY canal. Act 41 Geo. III.—The general direction of this canal is nearly S.W. for about 12 miles, by a crooked course in the county of Surry, and through a small part of Kent. It is not greatly elevated in any part: its objects are the supply of the neighbourhood through which it passes with coals, deals, manures, &c. the bringing of vegetables, and other articles for the supply of London: forming a communication between three points of the *Thames* river, and with the *Croydon* canal, which it joins near Deptford. It commences in the river *Thames* at Wilkinfon's gun-wharf in Rotherhithe, and is to terminate at the town of Mitcham; near Walworth a branch of about $\frac{1}{4}$ of a mile goes off to join the *Thames* at

Vauxhall creek by Cumberland gardens. There is to be a cut of near $1\frac{1}{2}$ mile to Horsefonger lane; another of $\frac{1}{2}$ a mile to Peckham; another of one mile to But-lane Deptford; another of $\frac{1}{4}$ of a mile to his majesty's victualling office and the dock-yard at Deptford, and another of $\frac{1}{2}$ of a mile into Greenland dock, by which it will again communicate with the *Thames* river.

From the river *Thames* to the junction of the *Croydon* canal the distance is 2 miles, and nearly level with high water in the tide-way of the *Thames*, at which height the water is to be held up by tide or entrance locks; thence to the Vauxhall branch at Kennington common it is 3 miles and level; thence to Brixton-causeway, $1\frac{1}{4}$ mile, it has a considerable rise; thence to the proposed Kingston branch, $4\frac{1}{2}$ miles, it is level; and thence to Mitcham town it is $\frac{3}{4}$ of a mile: the Vauxhall, Horsefonger-lane, Peckham, But-lane, King's yard, and Greenland-dock branches, are all level. This canal is calculated for wide or river boats: near the commencement, at Wilkinon's wharf, a large basin is designed, and a smaller one at But lane near the Greenwich road: across Rushey-green to Brixton-causeway an inclined plane is intended. Mr. *Ralph Dodd* was, we are told, the contriver of this canal, and under his directions the works were begun, and considerable progress made between Rotherhithe and the Peckham branch; but for more than two years past, little further progress appears to have been made. The company were authorized to raise 60,000*l.* in 100*l.* shares. The tonnage on this canal varies from 2*d.* to 6*d.* per ton per mile on different kinds of goods. The company are to pay a rent of 60*l.* per annum to the city of London for communicating with the *Thames* river. Collateral cuts to the extent of 1,500 yards may be made by consent of the land owners. In 1800, it was intended to extend this canal $6\frac{1}{2}$ miles further to the *Thames* river on the south side of the town of Kingston, which was to pass the *Surry* iron railway at Merton abbey, by an aqueduct bridge 11 feet high in the clear, and the Wandale river by another 15 feet above its surface; from Norbiton common this was intended to branch again to the town of Epsom, $5\frac{1}{2}$ miles, and from Mitcham the canal was there also proposed to be extended to the town of Croydon. In the same year there was also a proposal for extending the intended Kingston branch to the *Wey* river (near the commencement of the *Basingstoke* canal), as part of one of the lines between *Portsmouth* and *London*. The *Croydon* canal company are to have a dock or basin for their boats by the side of this canal near the *Thames* at Rotherhithe; which, with the entrance lock and basin of this canal, are now excavating, and seem on a scale calculated for small ships.

GRAND WESTERN CANAL. Act 35 Geo. III.—The general direction of this canal is nearly N.E. for about 35 miles, in the counties of Devon and Somerset: it crosses the south-western branch of the grand-ridge; its objects being a connection between the southern coast and the Bristol channel, the supply of the country with coals, deals, &c. and the export of farming produce. Exeter is the 21st British town, with a population of 17,398 persons; Wilington is the 73d, with 7,531 persons; Tiverton the 94th, with 6,505 persons, and Taunton, the 106th, with 5,794 persons; Topsham, Bradninch, and Cullumpton, are also considerable towns near this line; which commences in the tide-way of the river *Exe* at the town of Topsham, and terminates in the *Tone* river at Taunton bridge; it has a cut of about seven miles to Tiverton, and other short ones to Cullumpton and Wallington. It is provided, that the brick bridges shall not have a rise of more than $2\frac{1}{2}$ inches in a yard on the ascent of the road over them. Two reservoirs are to be made in the valley of the Culm river, and two in the

river *Tone* valley. Springs within 2000 yards of the line may be taken, and cuts to any place within five miles may be made by consent of the land owners. The company are authorized to raise 330,000*l.*, the amount of shares being 100*l.* each. We have not been able to learn that any progress is yet made in the cutting of this canal, although one through this line of country has been so long desired, as appears by Mr. *Brindley's* survey for the *Exeter and Up-hill* canal, that was proposed in the year 1769.

GRANTHAM CANAL. Acts 33 and 39 of Geo. III.—The general direction of this canal is nearly east, by a crooked course of $33\frac{1}{4}$ miles, in the counties of Nottingham, Leicestershire, and Lincoln: its eastern end is rather elevated. Its objects are the supply of Grantham and the neighbourhood through its course with coals, lime, deals, &c. and the export of farming products. Nottingham is the 17th British town, with 28,861 inhabitants; and Grantham the 85th, with 7,014 persons; Birmingham is also a considerable town. This canal commences in the *Trent* river, near Holme-pierpoint, (almost opposite the *Nottingham* canal, to the *Trent* canal, and to the town of Nottingham,) and terminates at the town of Grantham; there is a branch of three miles in length to the town of Bingham. From the *Trent* river to Cropwell-bishop, $6\frac{1}{2}$ miles, is a rise of 8*1* feet; thence to Stainwith-cloves, 20 miles, is level; thence to Woolthorpe point, $1\frac{1}{4}$ mile, is a rise of 58*1* feet; and thence to Grantham, five miles, is level: the cut to Bingham is level. This canal, which is through a clayey district, is wholly supplied by reservoirs, of which, one at Denton is 20 acres, and nine feet deep, for supplying the head-level; and that at Knipton for receiving the flood waters of the *Devon* river, was 60 acres, and nine feet deep, and in 1804, the bank or head of this last was raised four feet higher. The company were authorized to raise 124,000*l.*, the old shares being 100*l.* value each, and the new shares (200 in number) 120*l.* each. The tonnage on all goods passing to or from this canal and the *Trent* river is to be 2*1**d.* per ton, and 1*1**d.* per ton per mile for navigating on this canal: manures and road materials to pass toll free, except lime-stone, which is to pay $\frac{1}{4}$ *d.* per ton per mile. The *Newark and Bottesford* canal was at this time (1793) in contemplation to join this near Stainwith; and the tolls for entrance therefrom, or on goods passing into that intended canal, were settled in the first act above. The profits to the proprietors of this canal are limited to a dividend of 8 per cent. per annum, and after 3,000*l.* are collected and deposited as a fund, the above tolls are to be lowered, as much as circumstances will admit. The *Trent* river proprietors are to take certain tolls on goods passing into or out of this canal to the *Nottingham* canal, in consequence of their deepening the river near the entrances to these canals; and goods passing from this canal on the *Trent* are not to be liable to their new rates of 34 Geo. III. unless they pass on the *Trent* canal, to be made under that act above Nottingham.

GRESLEY'S CANAL. Act 15 Geo. III.—The direction of this canal is about N.W., and level, in the county of Stafford: it is situate very near to the grand-ridge on its eastern side. Its objects are the supply of the town of Newcastle under-line with coals from Apedale collieries, and the export of coals from the mines to the west of it, by means of the *Newcastle under-line Junction* canal, which now joins it at each of its ends. This canal was constructed at the sole expence of sir Nigel *Grisley*, bart., who was bound by the act, for 21 years after 1775, to supply the inhabitants of Newcastle with coals at 5*s.* 6*d.* per ton of 2,400*lb.* or 3*1**d.* by the single cwt. (of 120*lb.*); and during the following term of 21 years, their price was not to ex-

ceed 6s. per great ton. In 1796, the *Commercial* canal was proposed to connect with this canal at each end, as the *Newcastle under-line Junction* afterwards did in 1798.

GRIMSBY CANAL. Act 36 Geo. III.—This canal has a S.W. direction for $1\frac{1}{2}$ mile, in Lincolnshire: it is one of the largest cuts in England, and calculated to admit ships of 700 to 1000 tons burthen. It commences in the tide-way in the *Humber* river near its mouth, and terminates in the spacious wet-dock in Grimsby harbour. The lock to this canal is 126 feet long, 36 feet wide, and the walls are 27 feet high; the cost of it, we are told, was 14,000l. besides the piling for the foundation, although bricks were delivered there at 18s. 6d. per thousand, and stone at 8d. per cubic foot. The depth of water in this canal is 20 feet: it was constructed under the direction of that able engineer Mr. *John Rennie*. In the year 1804, three acres more surface was excavated in addition to Grimsby wet-docks, and the same was re-opened, after a temporary interruption, on the 24th of July.

HAMOAZE RIVER. This river, or rather estuary, has nearly a north course for about nine miles, between the counties of Cornwall and Devon on their southern coast: it is frequented by the largest ships of the royal navy. Plymouth is the 9th British town, with a population of 43,194 persons; Plympton-Earle and Saltash are also considerable towns near this estuary, which commences in Plymouth sound near Cawland bay, and terminates in the river *Tamar*, near St. Mellion. Near Warley the *Tavy* river falls into it; and Cat-water, Sutton-pool, and Stone-house creek, are branches from this estuary. In 1767, Mr. *John Smeaton* was consulted about a new bridge and causeway over Stone-house creek. In 1801, it was in contemplation to build a pier from Pinlee point for the better security of ships lying in Cawland bay from the E.S.E. winds. By an act of 45 of Geo. III. 4,000l. of the public money was voted towards cleaning and deepening Cat-water and Sutton-pool; and it is now in contemplation to construct a floating-dock in Sutton-pool capable of holding 100 merchants' ships always afloat.

Hampton Gay and Isleworth Canal. In the year 1792, a canal was proposed, to take a course nearly N.W. for about 60 miles, in the counties of Middlesex, Buckingham, and Oxford; commencing in the *Thames* river at Isleworth, and terminating in the *Oxford* canal at Hampton-Gay. It was intended to effect that junction between the metropolis and the midland canals, which the *Grand-Junction* now accomplishes: it was to pass the chalk hills by a tunnel at Wendover, and to have a cut of three miles to Aylesbury.

HARTLEPOOL CANAL. This is only a very short cut of 300 yards in length, on the coast of Durham, from the sea into Hartlepool harbour: it was cut in the year 1764, at the expence of sir John H. *Duval*, through a solid rock, to the great depth of 19 feet. In 1796, Mr. *Ralph Dodd* proposed, we are told, some improvements of this harbour.

HASLINGDEN CANAL. Act 33 of Geo. III.—The general direction of this canal is nearly north for 13 miles, in the county of Lancaster; it is considerably elevated, crossing the Haslingden and Liverpool branch of the grand-ridge. Its objects are the export of the rich stores of coal, limestone, &c. on its course, and a communication between Manchester and the *Leeds and Liverpool* canal. Bury is the 84th British town, with a population of 7,072 persons; Haslingden is also a considerable town. It commences in the *Manchester Boulton and Bury* canal at Bury, and terminates in the *Leeds and Liverpool* canal at Church. No

locks are to be built on this line, except by consent of three-fourths of all the millers who occupy the streams of water; it is intended to erect inclined planes. The company are authorized to raise 87,600l.; the amount of a share is 100l. The tonnage upon all kinds of goods which do not pass a lock or inclined plane, $1\frac{1}{2}$ d. per ton per mile; coals, or other mineral products, are to pay 2d., and timber, goods, wares, &c. 3d. per ton per mile, if they pass any lock or plane. Road materials (except for turnpike roads), and all manures, except lime, are to pass free on the levels, and through the locks when water runs waste over their weirs. Passage-boats are to be specially licensed by the company instead of paying tonnage. No wharfage is to be charged at the public wharfs, unless on goods remaining there above three weeks. We do not understand that much progress is made towards the completion of this canal.

Headon and Paul Canal. It is now (1805) in contemplation to form a canal from the *Humber* river at Paul to the town of Headon in Holderness, about three miles in the east riding of Yorkshire: its objects are the supply of Headon with coals and other articles, and the export of agricultural products.

HEREFORD AND GLOUCESTER CANAL. Acts 31 and 33 of Geo. III.—The general direction of this canal is nearly N.W. for $35\frac{1}{2}$ miles, in the counties of Gloucester and Hereford; the middle part of this canal is considerably elevated. Its object is the export of coals from the neighbourhood of Newent, and of the cyder and agricultural products of the country. Gloucester is the 72d British town, with a population of 7,579 persons; and Hereford, the 89th, with 6,828 inhabitants. Newent and Ledbury are also considerable towns on this line. It commences in the tide-way of the *Severn* river at Gloucester, crosses Alney Isle, and another branch of the *Severn* to Laffington, and terminates near the *Wye* river at Byfters-gate in Hereford; it has a short cut to Newent. From the *Severn* to Ledbury the distance is 18 miles, with a rise of 195½ feet; thence to Monkhide is 8½ miles on the summit-level; thence to Withington marsh it is three miles, with a fall of 30 feet; and thence to Hereford, six miles, it is level. Newent cut is level. On this line are three considerable tunnels, that at Oxenhal is 2192 yards in length; at Cannon-Frome is one of 1320 yards; and near Hereford, another of 440 yards in length. Mr. *Joseph Clowes* is the engineer; in July 1796, this canal was finished, from the *Severn* to Newent, and in March 1798, the Oxenhal tunnel was finished, and the navigation extended to Ledbury, and coals were in consequence reduced in price at that town from 24s. to 13s. 6d. per ton! The company were authorized to raise 55,000l. The prices of work in 1794, on this canal, 4d. per cubic yard for stages of 20 to 25 yards of wheeling: wheel-barrows were not used for moving stuff to greater distances than 100 yards; puddling cost 6d. per cubic yard. The rates of tonnage are for coals 2d. per ton per mile; for manures, bricks, and rubble stone, lime or clay, 1d. per ton per mile; corn, meal, hewn stone, hops, wool, and other goods, 3d.: there are also particular rates for certain parts of the canal. The cut across Alney Isle, owing to the tide of the *Severn*, entering it from each end, and dropping its sediment in the middle, is very liable to choak with mud. Springs or streams of water within 3,000 yards of the line may be taken for the use of this canal.

Hereford and Lydbrook. In 1802, it was proposed to construct a rail-way from the *Wye* river near the bridge in Hereford to join the same river again opposite to Lydbrook.

HEYL RIVER, (or Hale.) The course of this river or rather estuary is nearly south for two miles, in the county of Cornwall, on its north-eastern coast: it commences in *St. Ives* bay, and terminates at the town of *St. Erth*: it is navigable only for small vessels, being almost choked at the entrance of the bay. In 1766, Mr. *John Smeaton* was consulted on the building of a north-east pier at the entrance of *St. Ives* bay; the spring-tides here rise 26 feet.

HORNCASTLE NAVIGATION. Acts 32 and 40 of Geo. III. —The general direction of this navigation is nearly N.E. for about 11 miles, in the county of Lincoln; it is not much elevated above the sea: its objects are the supply of *Horncastle* and its neighbourhood with coals, deals, &c. and the export of agricultural products. *Horncastle* and *Tattershall* are considerable towns on this line. It commences in the old *Witham* river near *Tattershall*, and occupies the site of *Dylon's* and *Gibson's* former cut to *Tattershall*, passing that town to *Horncastle* by the course of the *Bain* river. The company were authorised to raise 45,000*l.*, the amount of each share being 50*l.* The dividends are not to exceed 8 per cent.; but after 1000*l.* is accumulated as a fund for contingencies, the tolls are to be lowered, to keep the profits within that limit. The first rates of tonnage are given in *Phillips's 4to. History, Appendix*, p. 24, but these were varied and increased by the last act above. This company purchased the old *Tattershall* canal, and were, by their first act, to contribute jointly with the *Witham* and *Sleaford* companies in the expences, during the next seven years, in improving and deepening the course of the *Witham* between *Lincoln* high-bridge and the *Fosse-dyke* canal, in order to facilitate the passage of goods to and from the *Trent* river, and in consequence, but half the accustomed *Witham* dues were to be paid for goods passing to and from this navigation. In September 1802, this navigation, and the basin at *Horncastle*, were completed and opened.

HUDDERSFIELD CANAL. Acts 33 and 40 of Geo. III. The general direction of this canal is south-west for 19½ miles in *Yorkshire* and *Lancashire*; it crosses the *Grand-Ridge*, at a great elevation, by one of the longest tunnels in this kingdom, in a rocky mountain: its objects are the carrying of coals that are found towards both its extremities, the supply of part of the country with lime, the conveyance of farming produce to the great towns, and the forming of a more direct communication between *Hull* and *Manchester* and *Liverpool*. *Huddersfield* is the 81st British town, with a population of 7268 persons: *Ashton-under-line* is also a considerable town. This canal commences in *Sir John Ramsden's* canal near *Huddersfield*, and terminates in the *Manchester Ashton and Oldham* canal, at *Duckenfield Bridge*, near the town of *Ashton-under-line* (near which the *P. & A. Forth* canal also joins it). From *Ramsden's* canal to *Marliden* the distance is 7¼ miles, with a rise of 436 feet; thence and through the tunnel to near *Saddleworth* it is 4 miles, and level; and thence to the *Manchester Ashton and Oldham* canal, 8¼ miles, is a fall of 334 feet. The lock at the entrance from *Ramsden's* canal is 8 feet wide, this canal being only intended for narrow and long boats. The Tunnel through the *Stannage Hills* near *Marliden* is to be three miles in length, near to which, on the summit-level, the company are authorised to make reservoirs to contain 20,000 lock-falls of water, (each 180 cubic yards), and may make others if these prove insufficient. About the year 1798, that part of the line between *Huddersfield* and *Marliden* was completed and opened; in the same year the head of a large reservoir near *Marliden* broke, and the torrent of water let down thereby did considerable damage to the country below it. The company are authorised to raise 274,000*l.*, the amount of shares being

100*l.* These became greatly depreciated in value, about the year 1800, owing principally, it is supposed, to many of the original subscribers not being able to answer the calls for money, by which the works were retarded, and the canal remained in an unproductive state: the Tunnel under the *Stannage Hill* is now proceeding. The rates of tonnage are from ¼*d.* to 3*d.* per ton per mile for different goods, (see *Phillips's 4to. History, Appendix*, pp. 135, 136.) besides which 18.6*d.* per ton is to be paid extra, on all goods which pass through the tunnel; less lading than 15 tons is not to pass any lock, unless the water runs waste thereat, without consent; no rates are to be taken by *Sir John Ramsden* for the goods which pass between his warehouses at *Huddersfield* and this canal, this company to amend and keep that part of his canal in repair, in consequence, and are to guarantee his tolls not being lessened, taking an average of three years before this canal is cut. This company is also bound not to make any branch or extension of the canal to any other navigation to the eastward; but, in such case, the tolls thereof are to be divided between *Ramsden's*, the *Culder and Hebble*, and *Ayre and Culder* proprietors, instead of being taken by this company.

HULL RIVER. The course of this river is nearly north for about 12 miles, in the *East Riding* of *Yorkshire*; it is but very little higher than the sea: its objects are the supply of *Beverley* and the adjacent country with coals, deals, &c. and the supply of *Beverley* and *Hull* with farm produce. *Kingston-upon-Hull* (or *Hull*) is the 16th British town, with 29,516 inhabitants; and *Beverley* is the 100th, with 6001 persons. This navigation commences in the tide-way of the *Humber* at *Hull*, and terminates in the *Driffeld* navigation upon the same river at *Aike-beck* mouth. In *Leven* parish (between *Eske* and *Leven-bars*) this is joined by the *Hull and Leven* canal.

HULL AND LEVEN CANAL. Acts 41 and 45 of Geo. III. The course of this canal is nearly east for about three miles, in the *East Riding* of *Yorkshire*; it is in a very low situation; its objects are the supply of *Leven* town, of lime to the country east of it, and the export of the agricultural produce thereof for the supply of *Hull* and *Beverley*. It commences in the *Hull* river, and terminates at *Leven* bridge. Mrs. *Charlotte Bethel* is the sole proprietor of this canal, on which Mr. *John Rennie*, Mr. *William Jessop*, and Mr. *James Creasby* were consulted. This canal was finished some time ago; and the act of last session was for raising the tolls, which were found disproportionate to the expence of its construction and management.

HUMBER RIVER. Act 23 Henry VIII.—This noble river, or rather estuary, has nearly a westerly direction for about 40 miles between the counties of *York* and *Lincoln*. The tide flows with great rapidity through its whole length, and the depth of water is sufficient for ships of considerable burthen, which trade in vast numbers to the port of *Hull*, and with the numerous eastern rivers which connect with it. *Hull* contains, as above stated, 29,516 inhabitants; and *Barton* is the 96th British town, with 6197 persons. *Grimby*, *Patrington*, *Headon*, and *Burton* are also considerable towns on or near to this river. It commences in the *German Ocean* at the *Spurn Head*, and terminates in the *Ouse* and the *Trent* rivers, at their junction at *Trent-fall*: it is joined at its mouth, near *Tetney*, by the *Louth* river; at *Grimby*, by the *Grimby* canal and docks; at *Kingston-upon-Hull*, by the spacious *Hull* docks and by the *Hull* river; in *Wintringham*, by the *Ancholme* river; and at *Fosse-dyke Clough*, near *Flaxfleet*, by the *Market-Weighton* canal. The port of *Hull*, and the accommodations of this river, have been greatly improved, by the constructing of

wet-docks at Hull; the acts 14, 42, and 45 of Geo. III. having passed for these purposes, the first dock was opened in September 1778. In 1800, the new Humber-dock was proposed, from Myton-gates to Hessel-gates, on the site of the old ramparts, to form seven acres of water, to which a 50 gun ship may have access from the *Humber*, and 70 sail of ships may lie constantly afloat, to be surrounded in part by spacious warehouses. By the act for the same, 30,000*l.*, in 1000*l.* shares, was to be raised; these shares have since borne a premium of near 50 per cent. The act of the late session was for raising more money to complete this vast undertaking, now in great forwardness. In September 1802, a small dock was begun on the shore of the *Humber* for market and ferry boats; a number of dolphins or floating buoys were, about the same time, placed on the banks of the river. In 1774, Mr. *John Smeaton* was employed to build two light-houses on the Spurn Head, at 300 yards apart, which, in June 1776, were in imminent danger of having their foundations undermined by a great storm: in September 1803, the lowest of these light-houses was burnt down by accident. Coal-ships, passing the *Humber's* mouth for the London market, pay 1*d.* on each chaldron of their cargo, towards the support of these lights. In 1800 it was in contemplation to erect a light-house at Stallingborough, on the south shore of the *Humber*. In 1802 the *Guttingham and Hull* canal was proposed, to connect with this river at Hull; in the same year, the *Keyingham-Level* navigation was proposed to join at Stone-creek. In 1805 the *Hradon and Paul* canal was proposed to connect with it at Paul.

IDLE RIVER. The course of this river is nearly west for about 10 miles, in Nottinghamshire: it commences in the *Trent* river at Stockwith, (near to the termination of the *Chesterfield* canal,) and terminates at the town of Bawtry. At half a mile from the *Trent* is Millerton sas or sluice, with an opening of 17½ feet, and two lock-doors 16 feet high, opening towards the *Trent*, to keep the floods thereof out of the low lands through which this river passes. In 1764, Mr. *John Smeaton* was consulted on this navigation and drainage.

INVERNESS AND FORT-WILLIAM CANAL. Acts 43, 44, and 45 of Geo. III.—This grand or *Caledonian* canal, as it is sometimes called, has nearly a south-west direction for 59 miles, in Inverness and Argyle shires, in the Highlands of Scotland; it passes the Grand-Ridge, through a low part thereof, intersected by deep lakes or lochs: its object is a connection between the East and West Seas, by Linnke Loch and Murray Firth, for large ships drawing near 20 feet of water, and for avoiding the northern voyage by the Orkneys, or through *Pentland Firth*. Inverness is the 63d British town, with a population of 873 persons. Nairn, Cromarty, and Fort-George are also considerable towns on this line. It commences in the tide-way in Loch *Beaully* at Clachnacarry basin, and, after passing through two large and two small inland lakes, it terminates in the tide-way in Loch *Eil* at Corpach basin. From the sea-lock at Clachnacarry to the 2d lock, about ¼ of a mile, it is level, with high water in Loch *Beaully*, and nearly parallel thereto; thence for one mile to the 6th lock is a rise of 45 feet by 5 locks; thence through Lochs Doughfour and Nefs to Fort Augustus is 28 miles, and level; thence to the east end of Loch Oich at the 13th lock, 5½ miles, is a rise of 53 feet by 7 locks; thence through Loch Oich, and the deep-cutting on the grand ridge west of it, is 54 miles and level; at the end of which the lock N^o 12, at the east end of Loch Lochy, makes a fall of 19 feet; thence through Loch Lochy to near Tor Caille is 10½ miles, and level; and

thence to the sea-lock at Corpach, 2½ miles, is a fall of 79 feet by 10 locks: in all 23 locks, besides the sea or entrance locks. This canal is 110 feet wide at top, 50 at bottom, and 20 feet deep; the locks are 152 feet long and 38 feet wide. At Clachnacarry and at Corpach are basins, each 400 yards long and 70 yards wide. Twenty-two miles of this navigation is through a surprising fresh-water lake, called Loch Nefs, of ¾ to 1½ mile in breadth, the middle part being 129 fathoms in depth! and its bottom muddy: this lock and the next never freeze, and it is said that the waters thereof do not corrode iron. Loch Lochy is another large lake, 10½ miles in length, and from ¾ to 1½ mile in width, and its greatest depth 76 fathoms, through which this navigation passes: it has a secure little harbour, 200 fathoms long and 150 fathoms wide, at its eastern end. Another smaller lake is found on this line, called Loch Oich, 3½ miles long, from ⅛ to ¼ of a mile wide, and 26 fathoms in depth in the deepest part, its bottom being a soft mud. Loch Doughfour, the remaining one of the four, is 1½ mile long, about ¼ of a mile wide in its widest part, and about 40 feet deep. The number of swing bridges is 23; there are 5 culverts with 1 to 4 arches each, and an aqueduct bridge of 4 ten-feet arches at Ley Bridge: the deep-cutting near Laggan is to be 15½ feet deep on the summit, and is estimated to cost 11,262*l.* New courses are required to be cut for the river Spean, and at Fort Augustus for the river Nefs; the steep hills adjoining, rendering it necessary for the canal to occupy the old bed of the river for some distance in those places. A large weir is to be made at the east end of Loch Doughfour, to hold up its waters to the level of Loch Nefs, and several smaller weirs are to be made. Loch Oich is to be deepened 1540 yards in length, at the expence of 11,550*l.* This canal is most amply supplied with water on the summit, not only for the lockage, but for the working of mills out of the different pounds, which will doubtless hereafter prove of immense advantage to the country. In 1774 Mr. *Watt* was employed to survey this line, who estimated a 12 feet deep canal, in the place of the present one, to cost 164,031*l.*, exclusive of the land. In 1801 Mr. *Thomas Telford* was employed by Government to survey the canal above described, assisted by Mr. *Murdoch Downie*, very full particulars of which will be found in the *Reports*, printed by order of the house of commons 14th June 1803 and 10th of April 1804; in which Mr. *William Jessop's* estimate, amounting to 474,531*l.* (exclusive of 23,000*l.* for land and mooring-chains) is given; and walled locks are recommended, on account of the loss of time in filling the chambers of those unwalled. By the first act above, 20,000*l.*, by the next 75,000*l.*, and by the last 50,000*l.* of the public money were granted, for carrying on this great work, under the direction of Mr. *Thomas Telford*. In October 1804, seven miles in length next Inverness were digging, and the entrance basins were in hand. In August 1805, the new channel for the river Nefs was cutting, the first lock new Inverness was building, 1000 men being employed at this end. It is proposed to place mooring chains on the shores of Lochs Nefs and Lochy, on account of their being too deep for good anchorage. On Loch Nefs government have had a galley of 37½ tons burthen since 1727, in which period, to 1803, five of them had been worn out: the worm so fatal to wood in some waters is not troublesome here. At Inverness the spring tides rise 11 to 15 feet, and the neap tides 7 feet; at Fort William they rise 12 and 5 feet. Cromarty Bay in Murray Firth, about 18 miles east of the beginning of this canal, was surveyed by Mr. *Thomas Telford* in 1801; the spring tides here rise 14 or 15 feet, and the two piers of this harbour appear to offer a safe retreat for ships, secure from

every wind, and where warehouses are only wanting for the accommodation of a large fleet.

ITCHING RIVER. Acts 16 and 17 of Cha. II., and 7 and 35 of Geo. III.—The general direction of this navigation is nearly north, for about 14 miles, in Hampshire; it is but little elevated above the sea; its objects are the supply of Winchester with coals, deals, &c. and of Southampton with flour and other agricultural products, and the trade between these towns. At Northam it is joined by the *Southampton and Salisbury* canal. Southampton is the 68th British town, with a population of 7913 persons; and Winchester the 153d, with 5826 persons. It commences in the tide-way in *Southampton Water* near Southampton, and terminates at Winchester. This navigation is the sole property of *James D'Arcy, Esq.*; and he and his predecessors were the sole carriers, or nearly so, thereon, until 1795, when commissioners were named, in the above act, for fixing rates of tonnage, on payment of which it is in future to be a free navigation. It was intended to widen the channel between Woodmill and the Roman ditch, and to erect pound-locks where necessary.

IVEL RIVER. Act 30 Geo. II.—The direction of this river is nearly south, for about 11 miles, in the county of Bedford; it is not very greatly elevated; its objects are the supply of the towns of Biggleswade, Shefford, and the adjoining country, with coals, deals, &c. and the export of farm produce. It commences in the great *Ouse* river at Tensford, and terminates at the town of Shefford. On the lower end of this navigation, sluices with separate and moveable upright planks instead of gates are in use, as before mentioned. Soon after the passing of the act, the navigation was completed to Biggleswade; but the remainder of the distance to Shefford, 5½ miles, has not yet been made navigable, for want of money. In the present year (1805) Mr. *Benjamin Bevan* was employed to survey and estimate the expence of this part, which he states at 5900l.; the rise about 26 feet, to be effected by 5 locks; the toll on this distance is to be 1s. 6d. per ton. It is stated that the part of this navigation below Biggleswade has, in the last seven years, produced a net 400l. per annum, towards the reduction of the debt at first incurred. Several years ago the *Biggleswade and Hertford* canal was proposed to join this river at Biggleswade.

IVELCHESTER AND LANGPORT CANAL. Act 35 Geo. III.—The direction of this navigation is nearly east for about 7 miles in the county of Somerset: it is not much elevated: its objects are the import of coals and export of farming products; Langport and Ilchester, or Ivelchester, are considerable towns; it commences in the *Parret* below the town of Langport, and terminates at the town of Ilchester, following the course of the *Yeo* river part of the way, and the remainder by a canal; the company were authorized to raise 8,000l., the amount of shares being 50l. each: half-mile flones are to be erected on this navigation.

KENNET RIVER. The course of this river is nearly east for about 20 miles in the county of Berks, it has a considerable elevation: its objects are the supply of Newbury, the export of farming products, and forming part of the most direct communication between London and Bath and Bristol; Reading and Newbury are considerable towns. It commences in the *Thames* river about a mile below Reading, and terminates in the *Kennet and Avon* canal a little above Newbury; on this navigation unwalked locks were very early in use; in Feb. 1800 it was proposed to improve this navigation through the borough of Reading. This company has given notice that as carriers, they will not be answerable for the damage goods may sustain by fire or unavoidable accidents. Immense beds of Peat are found near Reading, which is used for considerable distances as a manure.

KENNET AND AVON CANAL. Acts 34, 36, 38, 41, and 45 of Geo. III.—The general direction of this canal is nearly east for 55½ miles in the counties of Somerset, Wilts, and Berks. The middle part is considerably elevated, and crosses both the western and eastern branches of the grand-ridge, the part between these points, crossing the heads of the valleys which fall to the southern coast, while the ends are in those vales falling to the *Bristol Channel* and the *Thames*; its objects are a communication between Bristol, Bath, and London, and the supply of the country west of Hungerford with coals from the mines connected with the *Somersetshire Coal* canal, which joins at Monkton Combe; at Widford it connects with the *Dorset and Somerset* canal, and at Semington with the *Wilts and Berks* canal. Bath is the 12th British town, with 32,200 inhabitants; Devizes is the 69th, with 7,909 persons; Bradford the 78th, with 7,302 persons; and Trowbridge the 104th or 105th, with 5,799 persons; Melksham, Hungerford, and Newbury, are also considerable towns on or near this canal. This canal commences in the *Avon* river at Dole-Mead in Bath, and terminates in the *Kennet* river a little west of Newbury; the branches that were at first proposed to Calne and Chippenham, have been superseded by the *Wilts and Berks* canal, and its branches. From the *Avon* to near Bathampton ¼ of a mile is a rise of 56½ feet; thence to Trowle bridge, 10½ miles is level; thence to Devizes, 9½ miles, is a rise of 30½ feet; thence for 20 miles along the summit-pound (and through the tunnel of 2½ miles, at first proposed) to Crofton; thence to Hungerford is six miles, with a fall of 104 feet; and thence to the *Kennet* near Reading, 9 miles, is a fall of 72 feet. By the second act, the company were authorized to raise a part of their summit-pound at its eastern end, so as to pass the summit by a moderate deep-cutting instead of the tunnel above mentioned, and to supply the new summit with water by a large steam-engine. This canal is calculated for 50 ton boats; at Trowbridge there is a basin 129 yards long and 60 wide, and another between Lyncombe and Widcombe. There is a considerable deep-cutting near Burbage: there are two large stone aqueduct bridges over the *Avon* river, one called Dundas, the other is at Avon-cliff. Progress was first made in completing parts of this canal at its eastern end, and in October 1798, the same was opened from Reading to Hungerford; in July 1799 the same was opened to Great Bedwin, near the beginning of the summit; in May 1801, the other end of the line was opened from Bath to Devizes. The company were authorized to raise 810,000l. besides a farther sum by the last act; the original shares were 120l. each, but a great number of defaulters appeared among the subscribers, (no less than 470 shares it was said) and those remaining being called on for 17l. 4s. 7½d. on each, made the amount of these old shares 137l. 4s. 7½d. each, before the act of 41 Geo. III. restrained any further calls on their shares, and created a new set of shares of the amount of 60l. each. The shares of several discontented proprietors were directed to be purchased. This canal passes through Sydney-gardens near Bath, which are laid out and appropriated to pleasurable parties like our Vauxhall gardens. The rates of tonnage are from 1d. to 2½d. per ton per mile on different goods, and others are fixed for the distance between Bath and Devizes, for which see *Phillips's 4to. History, Appendix*, pages 142 and 143. Mr. *John Rennie* is the engineer, whose superior skill has been shewn in surmounting the great difficulties that have attended the construction of this canal: between Avon-Cliff and Bradford, a single slip cost, it is said, 1000l. repairing. A canal passing through nearly this tract of country was proposed in 1754. The new shares in 1802

bore a premium, notwithstanding no interest is to be received on them until the line is completed, which was required by the first act to be done in the next year, (1806); we sincerely wish this may be the case. Some years ago it was proposed to extend a branch of the *Basingstoke* canal to join this at Hamstead: in 1796 there was an intention of extending this canal by the side of the *Avon* to Bristol.

KETLEY CANAL. The general direction of this canal, or water-level, is about E.; originally it was about $1\frac{1}{4}$ mile in length, in the county of Salop; it has a great elevation, being within 7 or 8 miles of the grand ridge on its western side; its objects are the conveyance of coals, iron-ore, and lime-stone, the export of heavy iron goods, &c.; it was contrived by Mr. *William Reynolds*, and cut in 1788 at the sole expence of Messrs. *William Reynolds and Co.* and in the year 1793, 1 mile and 188 yards of this level at its east end were sold to the *Shrewsbury* company, and made part of their canal; the price was 840l. half the original cost, with the condition that Messrs. *Reynolds and Co.* should pay 2d. per ton per mile for their goods passing on the *Shrewsbury* canal. This canal now, therefore, consists of about three furlongs of level connecting with the *Shrewsbury* canal, at the head of the Wom bridge inclined-plane, and having at its other extremity an inclined plane of 73 feet perpendicular fall to the Ketley iron-works; this inclined plane was the first that was brought into practice in England for the passage of boats, and in 1789 a copper medal or half-penny was struck to commemorate the fame. The boats used hereon are 20 feet long, 64 feet wide, and 3 feet 10 inches deep, carrying 8 tons; they are floated into a shallow lock at the top of the plane in order to place them upon the wheeled carriage or cradle, which carries them down the plane, after the water in the lock is drawn off into a side-pond, to be pumped up again by a steam-engine into the upper pound, and by which no water is lost out of the upper pound or water level. The inclined plane is double, and a descending loaded boat draws up an empty one or but about one-third laden, by means of strong ropes winding round a barrel at the head of the plane, the velocity being regulated by a brake-wheel; of this plane we have before spoken. Several of these small boats linked together are towed along the level by one horse, and to guide them round the projecting turns of the bank, slide-rails are placed thereon.

Keyingham-Level. In the year 1802, Mr. *William Chapman* made a survey for a navigation, and drainage-cuts, from the *Humber* river at Stone-creek, to Roofs-bridge and Owtwick-carr gate, in the East-Riding of Yorkshire, the estimated expence thereof being 1500l.; the canal was proposed to pass near the town of Keyingham, its objects being the import of coals, &c. and the export of agricultural articles.

KIDWELLY CANAL. The length of this canal is about $3\frac{1}{2}$ miles, in Caermarthenhire, in South Wales, it is the private property of Mr. *Keymer*; it extends from the tide-way at the town of Kidwelly to Mancha coal and lime-works, belonging to Mr. *Keymer*, through whose estate the canal is also cut: its object is the export of lime and coals.

LAGAN NAVIGATION, (Ireland). This is one of the navigations which the Irish parliament have assisted with sums of money, with the view of facilitating the working of the collieries with which it connects; for this navigation and its collieries, various sums of public money were advanced between 1753 and 1770, amounting to 40,304l.

LANCASTER CANAL. Acts 32, 33, 36 and 40 of Geo. III.—The general direction of this canal is nearly S. for $7\frac{1}{2}$ miles, in the counties of Westmoreland and Lancaster; the greater part of its northern end skirts along near the sea-coast, but the southern end is considerably elevated,

crossing within two miles of its termination the *Hastingden* and *Liverpool* branch from the grand-ridge. Its objects are, the interchange of the lime-stone of the northern parts, for the coals and cannel of the southern parts of the line, the supply of Lancaster and Preston, &c.: it is to connect with the sea at Glasson Dock by a cut of 4 miles from Galgate on the line of the canal; it crosses the *Loyne* and *Ribble* rivers, but without connecting with them, and it likewise passes under the *Leeds* and *Liverpool* canal. Preston is the 37th British town with 11,887 inhabitants, Wigan is the 42d, with 10,989 persons, Lancaster the 56th, with 9,030 persons, and Kendal is the 88th, with 6,892 persons; Burton, Garflang, Kirkham, and Chorley are also considerable towns on this line. This canal commences in a basin at Kirkby-Kendal, and terminates in another at West Houghton: to Wharton-Craggs lime-works there is to be a cut of $2\frac{1}{2}$ miles, and another of $2\frac{1}{2}$ miles to Duxbury near Chorley. From the basin at Kendal to Greenhead farm (through the *Hincafter* or *Leven* tunnel) is $5\frac{1}{2}$ miles and level; thence to near Borwick, (near the Wharton branch) $9\frac{1}{2}$ miles, is a fall of 65 feet; thence to the south side of the meadows south of Preston is $42\frac{1}{2}$ miles and level; thence to Clayton Green $3\frac{1}{2}$ miles is a rise of 222 feet, and thence to West Houghton $15\frac{1}{2}$ miles is level; the Wharton and Duxbury cuts are level. This canal is 7 feet deep, the boats are 56 feet long and 14 feet wide, carrying 60 tons; and the *Glasfon* branch has a fall of about 52 feet. There are two tunnels, one at *Hincafter* near *Leven's* Park of about 800 yards long, and another through the *Whittle Hills* near Chorley, which proved a most difficult one to execute; at Ashton near Lancaster there is an amazing piece of deep-cutting. At Lancaster there is a most surprising aqueduct bridge 51 feet high, over the *Loyne* river, consisting of 5 arches of 70 feet span each. (See our article *BRIDGE*.) There are other aqueducts over the *Ribble* at Preston, the *Wyre* at Garflang, the *Beeloo* near Bethorn, &c.; and it is passed on an aqueduct 60 feet high near *Bark-mill* not far from Wigan by the *Leeds* and *Liverpool* canal. At Kendal the canal is supplied with water by a feeder of 1 mile in length from the river *Mint*: water from all mines within 200 yards may be taken. The part of the line between *Wheelton* (near to Clayton Green) and the south end of the long level is at present supplied with a rail way, but we believe only as a temporary measure. Mr. *James Brindley* was employed in 1772 to survey a part of this line, the whole of it was soon after surveyed by Mr. *Robert Whitworth*, and in 1791, Mr. *John Rennie* was employed, who has had the direction of the works upon it, which will redound to his lasting credit. The company is authorized to raise 414,000l. in 100l. shares, and 200,000l. more in shares of 30l. each. In July 1796, the last arch of the Lancaster aqueduct was completed: in September 1805, it was stated that the shares divided 1l. per cent. From Bolton to Lancaster and thence to Preston it was opened in November 1797, and in a few years after the whole of the long level was completed. In June 1803, the *Whittle* tunnel was completed, and $1\frac{1}{2}$ mile of the rail-way, so that coals passed from West Houghton to Bramber-bridge, and in 1805, the remainder of the rail-way was opened for conveying coals to Preston, Lancaster, &c. At West this canal passes along close to the sea beach. The rates of tonnage are, for coals $1\frac{1}{2}$ d. per ton per mile; for lime-stone, slate, salt, bricks, stone, iron-ore, gravel, sand, clay, and manures $\frac{1}{2}$ d. per ton per mile; for lime and iron 1d. per ton per mile, and for timber, wares, and merchandise, 2d. per ton per mile. Coals are not to pass the intended locks N. of Chorley under 2s. 3d. per ton, which is to pass them for 18 miles N. of Chorley. It is provided in

the *Ulverston* canal act (33 Geo. III.) that coals from this canal may cross the bay of Morecambe to that place without being subject to the sea duty.

LARK RIVER. This river (sometimes called the Milden-hall) has its course nearly S. E. for about 22 miles in the county of Suffolk, after skirting the bounds of Cambridge for some miles. Bury St. Edmunds is the 71st British town, with a population of 7,655 persons; Mildenhall is also a considerable town on the line of this navigation, which commences in the great *Ouse* river at Prick-willow, (about $4\frac{1}{2}$ miles below Ely) and terminates at Bury St. Edmunds. Its objects are the import of coals, deals, &c. and the export of farming products. The lower part of its course is embanked on both sides through the fens. It is generally very short of water in the autumn. In 1789, this river was proposed to be crossed by the *Bishopstortford and Wilton* intended canal; and in 1802 it was proposed to be joined at Bury St. Edmunds by the *Stowmarket and Bury* rail-way.

LEA RIVER. Acts 12 Geo. II. and 7, 19, and 45 of Geo. III.—The general direction of this river is almost north for about 28 miles, between the counties of Middlesex and Essex and in Hertfordshire; it is not much elevated. Its objects are the supply of Hertford and all the surrounding country with coals, deals, &c. and the export of farming products, of which malt from Ware forms a considerable part. At Bromley near Bow it connects with the *Lincolne* canal, and near Hoddesdon it is joined by the *Stort* river. Hertford, Ware, Hoddesdon, Waltham-Abbey, Enfield, and Stratford are considerable towns on or near this navigation. It commences in the *Thames* river at Bow-Creek near the *East-India Docks*, and terminates in the town of Hertford: it has a short cut to the town of Waltham-Abbey. This river, which seems subject to floods, was originally made navigable in some places by weirs and flush-sluices, or turnpikes. In 1767, Mr. *John Smeaton* calculated one of those sluices to let down $142\frac{1}{2}$ cubic feet of water per minute on an average, a consumption which greatly injured the mills; the early pound-locks erected on this river were without walled chambers. In 1771 some of the turnpikes were removed and locks built; in 1781, Mr. *Smeaton* was again called in to give an opinion on the very leaky state of the locks. In 1772, and again in 1802, this river was proposed to be joined at Waltham-Abbey by the *London and Waltham-Abbey*, with another junction therewith at Lee-bridge; and in 1792, it was proposed to be joined at Hertford by the *Leicester and London* canal. Several years ago the *Biggleswade and Hertford* canal was proposed to join this river at Hertford. Between Hertford and Ware, the *New River* or aqueduct for the supply of London, has its rise, partly out of the chalk hills, and partly by a feeder out of this river, and pursues its devious course for near 40 miles. This great work was begun by Sir *Hugh Middleton* in 1608; in 1773, Mr. *James Sharp* suggested the making of the *New River* navigable, and continuing it by a level cut to the *Thames* near Reading. In 1803, Mr. *John Rennie* was employed by government to survey the lower part of the course of the *Lea* river, and to construct embankments across, for filling this extensive vale with water in case of an invasion: the gates intended to produce these effects, are vessels that can on the shortest notice be floated to and sunk in their proper places, to stop the water, as before described.

Leatherhead and Thames Rail-way. In 1801, it was proposed to make a rail-way from a basin to be made on the banks of the *Thames*, in West Moulsey (opposite Sunbury) to the town of Leatherhead in Surrey, through the parishes of Walford, Cobham, Stoke-Dawbernon, Little Bookham, Great Bookham and Fetcham.

LEE RIVER, (Ireland.) For improving the navigation

of this river, the Irish parliament between 1753 and 1770, granted 2,000*l.* of the public money.

LEEDS AND LIVERPOOL CANAL. Acts 10, 23, 30, and 31 of Geo. III. The general direction of this canal is between N. E. and E. by a very crooked course of 130 miles, in the counties of Lancashire and York; it crosses the grand-ridge by a tunnel, near Colne, and at Red-Moss and Aspley crosses the Haslingden and Liverpool branch of the grand-ridge. Its objects are a communication between the ports of Liverpool and Hull, the export of the immense stores of coals, cannel, and lime-stone, that are found on parts of its course, and the supply of the great towns thereon with the agricultural products of the intermediate country. At Brierly mill it connects with the *Douglas* navigation (now belonging to this company, by a purchase under 23 Geo. III.); near Bark-mill not far from Wigan it crosses the *Lancaster* canal (but is 60 feet above it on an aqueduct-bridge.) At Church it connects with the *Haslingden* canal, at Skipton with *Thames*' canal, and at Windhill with the *Bradford* canal. Liverpool is the 4th British town with 77,653 inhabitants; Leeds is the 8th, with 53,162 persons; Blackburn is the 31st, with 11,983 persons; Wigan is the 42d, with 10,989; Bradford is the 95th, with 6,393 persons, and Huddersfield the 104th or 105th, with 5,799 persons; Ormskirk, Chorley, Burnley, Colne, and Skipton are also considerable towns on or near this line; which commences in the town of Liverpool (on the bank of the *Mersey*, but does not connect therewith) and terminates in the *Ayre and Calder* navigation in the town of Leeds; there is a cut to Lighton-hill collieries, another to Mr. Walton's Altham collieries; and provision is made for cuts to be made by the earl of Balcarras and Mr. Shuttleworth between their coal works and the line. The old basin at Liverpool is 52 feet above low-water mark in the *Mersey* river, from thence to Newborough, 28 miles, is level; thence to the beginning of the deviation that was last made in the line, near to the town of Wigan, 7 miles, is a rise of 30 feet, by 5 locks, (this last length being sometimes called the *Upper Douglas* navigation, of which it formerly was a part), thence to Bradshaw-hill near Aspley 3 miles, has a rise of 279 feet, by 28 locks, (the *Lancaster* canal being crossed in this distance) thence to the aqueduct over the Derwent near Blackburn, $19\frac{1}{4}$ miles, is level; thence to Grimshaw near Blackburn, $\frac{3}{4}$ of a mile, has a rise of $54\frac{1}{4}$ feet, by 7 locks; thence to the end of the deviation at Barrowford near Colne is 24 miles and level; and thence to the beginning of the summit pound near Colne is $\frac{3}{4}$ of a mile with a rise of $67\frac{3}{4}$ feet, by 7 locks. The summit-pound, passing through the Foulridge tunnel, extends to near Thornton, about $6\frac{1}{2}$ miles and level; thence to Holme-bridge near Gargrave is about $7\frac{1}{2}$ miles, with about 150 feet fall, by 15 locks; thence to Gawthorpe-hall near Bingley is 17 miles and level; thence to the junction of the *Bradford* canal is about 4 miles and 100 feet fall by 11 locks; and thence to the *Ayre and Calder* navigation at Leeds is about $12\frac{1}{2}$ miles, and 160 feet fall, by 18 locks: the whole lockage being $840\frac{1}{2}$ feet by 91 locks, which are each 70 feet in length, and $15\frac{1}{2}$ feet in width; the breadth of the canal; top is 42 feet, and it is $4\frac{1}{2}$ feet deep in water. The boats are keel-bottomed, and carry 30 tons of goods, with which they can go down the *Ayre* and *Ouse* as far as Seaby; between Leeds and Wigan, 100 flats of 42 tons burthen are employed in the coal and cannel trade, passage-boats also ply regularly on this part. At Leeds there is a fine basin, and there are spacious warehouses belonging to this company at the north-east corner of Liverpool town, and it was intended in 1801, to construct a new basin from the North Graving-Dock on this canal, to the top of Plumbe-street, for which

7000 cubic yards of earth were to be excavated, and the whole to be lined by 1200 cubic yards of stone masonry. The coals are thrown out of the boats on a branch that proceeds near to the *Mersey*, and slide down a steep bank to a yard by the water side. At Foulridge there is a tunnel of 1030 yards in length, and 23 yards below the highest point of the hill; the soil of which proved so very loose, that only 700 yards could be worked under-ground, the remainder was obliged to be opened from above, from 10 to 20 yards deep, and 20 to 30 yards wide at the top, although it was supported with immense labour and expence by timbers to prevent its falling, until the tunnel arch was formed, which is 18 feet high and 17 feet wide within; it is arched with stone. At Furnley near Burnley, there is another tunnel. At Cottingley below Bingley, and near Gargrave there are considerable aqueduct bridges over the Ayre river, and several lesser ones in different places. Mr. Longbottom made a survey for this canal in 1767, which was revised by Mr. James Brindley in 1768, under whom the canal was begun, after which Mr. Robert Whitworth and Mr. Fletcher were employed thereon. In 1770, the eastern end of the line was completed from Leeds to Holme-bridge, a distance of $3\frac{1}{2}$ miles; about the end of 1794 this was extended to near Foulridge. May 1, 1796, the Foulridge tunnel was completed and the line opened to Burnley. In May 1801, the Furnley tunnel was finished, and the navigation extended to Enfield within $4\frac{1}{2}$ miles of Blackburn; and in July 1801, the Altham branch was opened. The western end of the line was begun as early as the other, and in 1770 the same was opened from Liverpool to the *Douglas* old navigation at Newborough, 28 miles; and on 19th October 1774, the present navigation was completed to Wigan. This company was authorized to raise 600,000l. the amount of shares 100l. The rates of tonnage are, on lime-stone and other stones 1d. per ton per mile, on coals and lime 1d. and on all other articles $1\frac{1}{2}$ d. per ton per mile. No wharfage to be taken unless goods remain 6 hours. In September 1805, the company proposed lowering their rates of tonnage on the *Douglas* lower navigation. About the year 1794, a branch of the *Manchester Bolton and Bury* was proposed to join this canal at Red-Moss near Wigan. In September 1802, it was proposed to make a branch from this canal near Wigan to *Brigewater's* canal at Pennington; also a branch or rail way from it to Low-hall collieries.

LEICESTER NAVIGATION. Acts 31, 34, (for *Asby* Canal) and 37 of Geo. III.—The general direction of the line of this navigation is about south, following nearly the course of the Soar river, for 14 miles in the county of Leicester, its Charnwood Forest branch is considerably elevated. Its objects are the supply of Leicester with coals, deals, and general merchandize, the export of coals and limestone from the mines on its branches, and the farming products of the country. On the completion of the *Leicester Union* canal it will become a considerable thoroughfare. At Turn-water Meadow in Cossington, it is joined by the *Leicester and Melton-Mowbray* navigation. Leicester is the 22d British town with a population of 16,953 persons; Loughborough and Mount-Sorrel are also considerable towns on the line. It commences in the basin of the *Loughborough* navigation at that town, and terminates in the *Leicestershire and Northamptonshire Union* canal, at Leicester. From the basin at Loughborough, a rail-way branch of 24 miles, and a rise of 185 feet, extends westward to a basin at Forest-lane, at the east end of the Charnwood Forest water-level, which level extends $8\frac{1}{2}$ miles to near Barrow-hill, having a side cut of $\frac{1}{2}$ of a mile to Thringstone-bridge, and level. From the west end of the water-level a rail-way extends $\frac{2}{3}$ of a mile further to Cloude-hill lime-works, and there connects or very nearly so

with a branch of the *Asby-de-la-Zouch* canal; there is a short rail-way branch of six chains to Barrow-hill lime-works; the Thringstone-bridge branch is also continued by a rail-way to Coal-Orton in two branches of $1\frac{1}{2}$ mile, and another of $\frac{1}{4}$ of a mile to Swannington-common coal-works. From *Loughborough* basin to the junction of the *Leicester and Melton-Mowbray* navigation it is 3 miles, and level, and thence to the *Leicestershire and Northamptonshire Union* the distance is 11 miles, with a rise of 45 feet. On Charnwood Forest there is a reservoir for supplying the water-level, and a feeder of $\frac{3}{4}$ of a mile in length to convey the water to it. Near the west bridge in Leicester there is a basin for the use of this navigation. Mr. William Jessop was the engineer; in December 1793 the part of the line between Loughborough and Sielby, near Mount Sorrel, was opened, and in February 1794 the remainder of the same to Leicester was opened. The company was authorized to raise 84,000l. The rates of tonnage are various: see *Phillips's 4to. History, Appendix*, p. 12. On the making of the *Asby* canal, with branches to the neighbourhood of the collieries connected with the Charnwood level, the company were allowed 2s. 6d. per ton on all coals dug in Swannington, Coal-Orton, or Thringstone parishes, and carried through Blackfordby, on the *Asby* canal. The company are authorized to make rail-ways to any mines within 2000 yards of the water-level; and are to guarantee the *Loughborough* company a receipt of 2000l. per annum, on condition of their taking 1s. 6d. or less per ton (but not less than 10d.) for coals passing from Loughborough to the *Trent* river.

Leicester and London Canal. About the year 1792 printed proposals and a plan were circulated, for a canal from the *Leicester* navigation at that town to the *Lea* river at Hertford, a distance of 77 miles; passing Market-Harborough, crossing the *Nen* river near Wellingborough, and connecting with the *Ouse* navigation at Bedford; its proposed object, as a rival to the *Grand Junction*, was the forming of the shortest communication between London, Liverpool, Hull, and Lynn, and the intermediate large trading towns, mines, &c.

LEICESTER AND MELTON-MOWBRAY NAVIGATION. Acts 31 and 40 Geo. III.—The general direction of this navigation is nearly E. following the courses of the *Wreak* and *Eye* rivers, for about 12 miles, in the county of Leicester; it is not greatly elevated in any part, its objects are the supply of Melton-Mowbray with coals, deals, &c. and the export of the farming products of the country; it commences in the *Leicester* navigation at Turn-water Meadow in Cossington, and terminates in the *Oakham* canal, at the town of Melton-Mowbray. The company were authorized to raise 40,000l. The original rates of tonnage may be seen in *Phillips's 4to. History, Appendix*, p. 13, but these were altered and increased by the late act above, and several regulations made respecting tolls with the *Oakham* company. This navigation was completed in a few years after the passing of the first act.

LEICESTERSHIRE AND NORTHAMPTONSHIRE UNION CANAL. Acts 33 and 45 Geo. III.—The general direction of this canal is nearly S.E. by a crooked course of 434 miles in the counties of Leicester and Northampton; its middle part is considerably elevated, and skirts along the eastern side and near to the grand-ridge for several miles: its objects are the formation of a junction between London, Hull, and Lynn; the supply of the country through which it passes with coals, deals, &c. and the export of farming products; it is to connect at Northampton with a rail-way branch of the *Grand Junction*. Leicester is the 22d British town, with a population of 16,953 persons, and Northampton is the 85th, with 7,020 persons, Market-Harborough

is also a considerable place near the line. This canal commences in the *Leicester* navigation in the town of Leicester, and terminates in the *Nen* river at the town of Northampton; there is a cut of $3\frac{1}{2}$ miles in length to Market-Harborough. From the *Leicester* navigation to Fleckney near the Saddington tunnel is $12\frac{3}{4}$ miles, with 160 feet rise; thence to near Great Oxenden $13\frac{1}{4}$ miles are level; thence in $\frac{1}{4}$ of a mile is 50 feet rise; thence the summit-pound extends through Oxenden and Kelmarsh tunnels to near Maidwell, $4\frac{1}{2}$ miles and level; thence to the junction of the North river near Northampton are $11\frac{1}{4}$ miles, with a fall of 197 $\frac{1}{2}$ feet, and thence to the head of the *Nen* navigation is $\frac{3}{4}$ of a mile and level. The Market-Harborough cut is level. At Gumley there are a bafon and warehouses. There are four tunnels on this line, viz. at Foxton, of 1056 yards in length; at Kelmarsh, of 990 yards in length; at Saddington, of 880 yards in length, and at Oxenden, of 286 yards in length. On Oxenden and Kelmarsh brooks are the aqueducts for the supply over the summit-level, but flood-waters alone are to be taken. There are a great number of small aqueducts over the streams which it passes. Mr. John Varley, sen. and Mr. C. Stankly, jun. are the engineers. In March 1800, the tunnel at Saddington was finished, and the line opened from Leicester to Gumley, a distance of 17 miles; but small progress appears to have been since made with the other three tunnels, and the remainder of the line, intended to form the union. The rates of tonnage on coals and coak are 2 $\frac{1}{2}$ d. per ton, per mile, but not to exceed 5s. for any distance; for lime, lime-stone, dung, and manure 1 $\frac{1}{2}$ d. per ton, per mile, but not exceeding 2s. 6d. per ton, on any distance; for live cattle, stones, bricks, tiles, slates, sand, iron-stone, pig-iron, and pig-lead, 2d. per ton, per mile, and for other goods 3d. per ton, per mile; troops and government stores are exempted. Road-materials, and manures (except lime) for the use of the proprietors of lands on the pounds, may also pass the locks when the water runs waste thereat. The towing path may be used as a bridle and drift-way by the owners of adjoining lands. By the first act the company were authorized to raise 500,000l. shares 100l. each; the last act was for varying some parts of the line and amending the former one. About the year 1753, the *Uppingham* canal was in contemplation, and its junction with this canal is provided for in the first act above. In 1803 it was proposed to alter and shorten the branch to Market-Harborough, and to make a feeder from Willow brook; and in the same year Mr. Thomas Telford surveyed the line of country between Gumley bafon and Buckby wharf on the *Grand Junction* canal, proposed as a substitute for the southern part of the line to Northampton.

LEOMINSTER CANAL. Acts 31 and 36 Geo. III.—The general direction of this canal is nearly W. by a crooked course of $45\frac{1}{2}$ miles, in the counties of Worcester, Salop, and Hereford; its western end is very considerably elevated; its objects are the supply of Leominster and the country with coals from the Pinfax mines near its eastern end, and the export of iron, lime, and agricultural products: Kingston, Presteign, Leominster, Ludlow, Tenbury, Cleobury-Mortimer, and Bewdley are considerable towns on or near to the line of this canal: it commences in the *Severn* river at Areley near Stour-port, and terminates at the town of Kingston: it has two short cuts to mills near Tenbury. From the *Severn* river to the east end of the Pinfax tunnel it is 3 miles, with a rise of 207 feet; thence through that tunnel, and the Soufnant tunnel to its western end, it is 9 miles and level; thence to the river Rea aqueduct is 1 mile, with a fall of 30 feet; thence to Letwich brook, 7 miles, it is level; thence to Wilton, $4\frac{1}{2}$ miles, is a rise of 36 feet; thence to near Luston, $5\frac{1}{2}$ miles, is level; thence to Leominster, $1\frac{1}{2}$

mile, is a fall of 18 feet; thence to near Kingsland are $4\frac{1}{2}$ miles, with 64 feet rise; thence to Milton are $3\frac{1}{2}$ miles, with 37 feet rise; thence to Stanton-park are $2\frac{1}{2}$ miles, with a rise of 152 feet, and thence to Kingston are 4 miles, and level. At Pinfax is a tunnel of 3850 yards, and the other at Soufnant is 1250 yards in length. There are considerable aqueduct-bridges over the Rea river at Knighton, over the Teme at Woferton, and over the Lugg at Kingsland: a power is provided in the act for inclined-planes instead of locks, if the same should be found most eligible; springs of water within 2000 yards of the line may be taken. Mr. Thomas Daisford, jun. is the engineer. In July 1796 the difficult tunnel at Putnal-field in Soufnant was finished, and in November 1796, near 20 miles of canal, from Mumble coal-works to the town of Leominster were opened, and coals, which before sold there at 18. 6d. per cwt. were at once reduced to 9d. per cwt. On the 1st of June 1797, the entrance of the canal from the *Severn* was opened: since which considerable progress has been made in the works: in May last (1805,) the Pinfax mining company was proposed, for opening new coal and iron mines near that place, on the line of the canal, which was expected to facilitate its completion. The *Leominster* company have been authorized to raise 370,000l. The tonnage rates are too long for our room, they will be found in *Phillips's 4to. History, Appendix*, p. 5 and 6. About the year 1794, the *Wellspool* and *Leominster* canal was proposed to join this at Woferton.

LIFFEY RIVER, (Ireland). The direction of this river is nearly west, in Dublin county, from the bay of Dublin to the entrance bafon of the *Grand Canal* in Dublin city, where also are a Harbour and Docks that have been improved, under Mr. William Jessop; the spring tides rise only 13 feet at these dock-gates. In the year 1800 it was proposed to avoid the bar at the mouth of the *Liffey*, by cutting a new channel or canal for ships from Dunleary to Ringstead dock; it was also proposed to make Dalkey sound a safe harbour, and to make a cut from thence to the *Grand Canal* bafon; the bill for this purpose was passed by the commons, but was rejected by the house of lords. Ormond bridge, on this river, was carried away by a flood, and in September last (1805,) the corporation of Dublin harbour offered premiums for the best plans for a new bridge at this place.

LIMEHOUSE CANAL. The direction of this canal is about N.E. for $1\frac{1}{2}$ mile, in the county of Middlesex; it is but little elevated above the level of the sea; its object is to shorten the navigation between the *Lea* river and the port of London, by avoiding the circuit round the Isle of Dogs; it commences in the river *Thames* near Limehouse church, and terminates in the *Lea* river at Bromley near Bow, having a rise of $17\frac{1}{2}$ feet. This canal was cut at the expence of the city of London, in an early part of the present reign, and its locks, which are of wood, and its other works, form a great contrast to the improved locks and appendages of modern canals. In 1773 a cut from the intended *London and Waltham-Abbey* canal was intended to join this near Limehouse church.

LIMERICK CANAL, (Ireland). This canal was cut near 40 years ago from the town of Leitrim to a morass within a short distance, for the purpose of bringing turfs, to supply the town of Limerick with fuel, and which by their cheapness superseded in a great measure the use of coals, which coming by a long coast-ways navigation were very dear.

Liskeard Canal. In 1777, Mr. Edmund Leach proposed a canal, or rather a system of water-levels and inclined-planes, from the tide-way in the *Looe* river, at Sand-place in Morval to Bark-mill-bridge, in St. Clear; this was proposed to be accomplished by two levels of 9 and 6 miles in

length, (one of which, in its serpentine course, went within $\frac{1}{2}$ a mile of Lifkeard town,) connected with each other and the river below by two inclined planes for boats, the principles of which have been already explained; the estimate was 17,500l. The objects of this navigation were the carrying up of lime and sea-sand for manure, and exporting corn, &c.

Liverpool and Runcorn. About the year 1771, a survey was made by Mr. James Brindley, for a canal from the town of Liverpool upon one level, to cross the Mersey at Runcorn-gap, by an aqueduct bridge, and join the duke of Bridgewater's canal; besides the great width of the Mersey at this place, a tide, which rises 14 feet, was also to be encountered.

Llandovery and Llanelly. In September 1801, notices were given for an intended canal from Spitty in the parish of Llanelly, on the Burry river, through Llangennech, Llanedy, Landebye, Llandingar, &c. to Llandovery or Llanyneddyvi, in the county of Caermarthen in South Wales. The objects of this canal were since accomplished by the *Caermarthenshire* rail-way, over nearly the same tract of country.

London Canal. In July 1802, a survey was made for a canal, about in a west direction, for near 7 miles, in the county of Middlesex: commencing in the *London Docks*, (and thereby communicating with the *Thames* river,) to pass West's-gardens, the mount in White-chapel road, and Bethnal-green New road, across Hackney road, through Middlesex-place across Kingsland road, near Iron-monger's alms-houses, to pass north of Lady Lumley's alms-houses at Hoxton, across the city road below the turnpike-gate, across Goswell-street, south of Goswell-place, across St. John's-street, north of Taylor's brewhouse, under the field south of the New-river head, over the valley at Bagnige-wells, across Gray's Inn-lane at the west corner of the Welsh Charity-school, across the New road to the east corner of Bedford nursery, across Tottenham court road between St. James's burying-ground and the New-river reservoir, past the fronts of the Artichoke and Queen's-head public houses, and across the Edgeware road to the basin of the *Grand Junction* canal at Paddington, the rise in this distance being about 90 feet. The great number of bridges required, the passing of the field near Ilington full of water-pipes in all directions, belonging to the New-river company, by an arch under the same, and a large embankment or aqueduct bridge near Bagnige-wells, were difficulties in the way of this project, but to which the subscription for shares (which almost immediately filled to the amount of 400,000l.) would have been equal; had not the inability of the *Grand Junction* company to furnish the water necessary for the lockage, and the opposition of several powerful land owners, on account of its making some alterations necessary in their building projects, frustrated the scheme altogether for the present. The western branch of the *Grand Junction*, of which we have before spoken, was in contemplation at the time this canal was intended, and water was proposed to be obtained thereby from the *Thames* for this canal, the Colne millers having it unfortunately in their power, to prevent any being obtained from that river; Mr. John Rennie, who gauged the stream of the *Thames*, in the dry summer of 1794, at Laleham (which is after it has received the main streams of the Colne), found 1155 cubic feet of water to pass in one second of time, which is 184 times what would be required to be taken from this river higher up near Great Marlow, and brought by the *Grand Junction* level branches, for supplying the lockage of this canal, supposing 60 locks containing 1055 cubic feet each, to be used daily. After the

opposing interests were found too strong to leave any prospects of carrying this canal, a faint effort was made to accomplish a rail-way, through nearly the same line, but with no better success. In 1773, Mr. Robert Whitworth made a survey for the city of London, and recommended a line of canal from the *Lea* river at Lee-bridge, to near the same spot which the *Grand Junction* basin now occupies at Paddington: it was intended as branches east and west of the *London* and *Waltham-Abbey* canal.

London Lynn and Norwich. In the year 1785, Mr. John Philips published a thin 4to. treatise, to endeavour to call the public attention to a canal between the *Ouse* river at the port of Lynn, and the *Thames* river at Limehouse in London, with a branch to the *Tare* river at Norwich. It appears that Mr. P. travelled through the proposed tract of country in 1779 and 1780, but took no levels or other necessary particulars, yet ventures to state, that he could execute this canal, 36 feet wide, and $4\frac{1}{2}$ feet deep, for 200,000l. And it is held out, that 28,000 oak Trees, to be planted on the banks of this canal, will, in 50 years, repay all its expences within 60,000l. In 1802 we are told that Mr. Ralph Dodd made an effort to revive this or a similar scheme, and wished to denominate it the North London Canal.

London and Waltham-Abbey. In the year 1773, at the instance of Mr. James Sharp, Mr. Robert Whitworth was employed by the city of London to survey the line for a canal between the centre of the quarters in Moorfields, London, to the river *Lea* at Waltham-Abbey; a distance of 14 miles, almost in a north direction in the counties of Middlesex and Hertford; this line was to be level (and about 30 feet above spring-tides in the *Thames*,) there was a cut of $\frac{1}{4}$ of a mile, and 33 feet fall proposed to the *Lea* river at Lee bridge, and another of $4\frac{1}{2}$ miles to Wellin's Farm near Paddington, with $49\frac{1}{2}$ feet rise; nearly to the same level as the *Grand Junction* basin now has; also another cut of near 2 miles to the Limehouse canal near the church, with a fall of 42 feet (to the common neap tides in the *Thames*). The width was to be 60 feet, and depth $4\frac{1}{2}$ feet; in Moorfields and near Holywell Mount, large basins were intended; between Stamford-hill and High-cross a very large embankment was necessary, another at Hackney brook, and another at St. Pancras brook; at Ponder's end was to be a deep-cutting to avoid the houses; 15 turnpike road-bridges, and 22 road-bridges of lesser size were necessary, the whole expence Mr. Whitworth estimated to be 98,229l. In 1802, this or a similar scheme seems to have been in contemplation, but to join the *Thames* near Bell-wharf in Shadwell instead of the Limehouse cut.

LOOE RIVER. The general direction of this navigation is nearly N. for about $3\frac{1}{4}$ miles, on the south coast of Cornwall, it commences at the sea near East Looe, (which is a considerable town,) and terminates at Morval bridge, near which, at Sand-place, it was, in 1777, proposed to be joined by the *Liskeard* canal; its objects are the carrying up of coals, and sea-sand as manure, and the export of agricultural products.

LOUGHBOROUGH NAVIGATION. A& 16 Geo. III.—The general direction of this navigation is nearly S. for about 9 miles, following the course of the Soar river, except in the last mile, which is a new cut; it is but little elevated; at the basin, 300 yards from its south end, it is joined by the line of the *Leicester* navigation and by the Charnwood-Forest rail-way branch belonging thereto. It commences in the *Trent* river (nearly opposite to the *Erweash* canal, and near to the *Trent* canal) near Sawley, and terminates at the Rushes near the town of Loughborough, which is a

considerable place; its objects are as various as the trade of the *Trent*, and the wants of Leicester and other great towns; it forms also part of the line of communication which the *Leicestershire and Northamptonshire Union* canal is to open. On the making of the *Leicester* navigation, that company guaranteed the amount of the tolls on this, to amount to 3000l. annually, on condition of no more than 18. 6d. per ton on coals or less than 10d. being taken by this company.

LOUTH NAVIGATION. The general direction of this navigation is nearly S.W. for 14 miles in the county of Lincoln, it is but little elevated above the sea; its objects are the supply of Louth, and the adjacent country with coals, deals, &c. and the export of farming produce; it commences at the sea-lock and ebb-gates in Titney Haven (at the mouth of the *Humber* river), and terminates at the town of Louth. From Titney Haven to the Louth river near North Cockerington $9\frac{3}{4}$ miles is level, and but little higher than low-water mark, being a new cut through a low fenny country; thence to Kiddington old mill, $2\frac{3}{4}$ miles, is 24 feet rise; thence to the Leather-mill meadow, $\frac{3}{4}$ of a mile, is $11\frac{1}{2}$ feet rise; thence to Louth is $\frac{3}{4}$ of a mile with 21 feet rise. Mr. John Grundy made a survey of this line, which was revised by Mr. John Smeaton, in 1760, the estimate of expence being near 15,000l. See *Smeaton's Reports*, vol. i. p. 25.

LOYNE RIVER. The general direction of this river (sometimes called the Lune) is nearly N.E. for about 7 miles in the county of Lancaster; the tide flows through its whole length; its object is the foreign trade of Lancaster, particularly in cabinet-maker's wares, a branch of the *Lancaster* canal is to connect with it at Glasson, where a spacious wet-dock is intended. Lancaster is the 56th British town with 9,030 inhabitants; this river commences in the Irish sea at Sunderland point, and terminates at Lancaster old bridge, some distance below Mr. Rennie's famous aqueduct bridge over this river. It appears, that in the year 1799, 52 vessels cleared out of this river for the West Indies with 11,669 tons of goods in more than 90,000 packages, worth $2\frac{1}{2}$ millions sterling. In October 1799, it was in contemplation, to construct a spacious dock at Thornbush for large ships, with a canal from thence of 6 miles in length through Glasson-dock, and nearly up to the town of Lancaster, to be wide and deep enough for the largest vessels that trade to that place.

LYNN RIVER. The general direction of this river (sometimes called the Lenne, the Nar, or the Setchy) is nearly S.E. by a crooked course of about 15 miles in the county of Norfolk; it is not greatly elevated in any part; its objects are the import of coals, deals, &c. and the export of farming produce; Lynn is the 50th British town with a population of 10,096 persons, Narford is also a considerable town; it commences in the Great Ouse river near the harbour of Lynn, and terminates at the town of Narford.

Macclesfield and Leek. In 1796, it was said, that a canal between these places was in contemplation, with extensions thereof to the Staffordshire potteries, in all 29 miles, on which no locks were to be used. Macclesfield is the 61st British town with 8,743 inhabitants.

Maidenhead and Isleworth. In the year 1770, Messrs. James Brinlley and Robert Whitworth, were employed by the city of London, to survey the line of a canal from the *Thames* river at Isleworth, to the same river again below Bolter's-lock near Taplow-mill, about 1 mile above Maidenhead-bridge, and at the lower end or termination of the 3d district of the *Thames and Isis* navigation; the length of this line is $19\frac{3}{4}$ miles with a rise of $71\frac{1}{2}$ feet. The canal was proposed to be 50 feet wide and 4 deep, with cuts to the *Thames* at Windsor, and near Laleham; in the first 5 miles

7 locks were to be built, and one in the remaining distance; the estimate of expence was 47,885l. A bill for this was brought into parliament, but the opposition of the landowners proved fatal to it; although, as appears, by an accurate measurement and section of the river between these two points made by the above engineers (see *Gentleman's Magazine for March 1771*), that the length of the river-navigation is $37\frac{3}{4}$ miles in this distance, and greatly obstructed by shallows, some only $2\frac{1}{2}$ feet deep in dry seasons. In the year 1791, this scheme was revived, and in 1794, Messrs. Robert Whitworth and Robert Mylne were employed to revise this line; their design has 12 miles of level at the upper end, and 10 of them straight; the canal to be 5 feet deep. The tolls at first proposed were $\frac{1}{2}$ d. per ton per mile on all articles; out of this revenue, it was proposed to improve the river navigation between Mortlake and Bolter's-lock: and to raise the necessary sums on life annuities, so that after a fund was established for repairs and management, the canal might at length become free for the public use. At Bolter's lock the *Reading and Maidenhead* canal was proposed to join this canal, by which the navigation from London westward would have been amazingly shortened and improved.

MANCHESTER ASHTON AND OLDHAM CANAL. Acts 32, 33, 38, 40, and 45 of Geo. III.—The general direction of this canal is nearly E. for about 7 miles in the counties of Lancaster and Cheshire; its eastern end is considerably elevated; its objects are the supply of Manchester and Stockport with coals, cannel, stone, lime, &c. and forming part of the intended direct communication between Liverpool, Manchester, and Hull, by means of the *Huddersfield* and other canals; by means of its Duckenfield branch it communicates with the *Peak-Forrest* canal. Manchester is the 2d British town with 84,020 inhabitants, Stockport is the 29th with 14,830 persons, and Oldham the 35th with 12,024 persons, Ashton is also a considerable town, and the country round about is full of inhabitants. This canal begins in the *Rochdale* canal near Piccadilly street in Manchester, and terminates in the *Huddersfield* canal at Duckenfield bridge, in the parish of Ashton underline; from Duckenfield bridge is a branch of $\frac{1}{4}$ mile in length, over an aqueduct bridge on the Tame river at Walk-mill, into Duckenfield, there to join the *Peak-Forrest* canal. There is a branch of 1 mile to Ashton town, another of $3\frac{1}{2}$ miles to New Mill in the parish of Oldham (but $2\frac{1}{2}$ miles distant from the town), from which last at Boodle-wood a branch proceeds over Water-Houses aqueduct on the Medlock brook, to Park collieries at Stake-Leach near Hollingwood, also in the parish of Oldham; from Droylsden, a branch of 6 miles proceeds to the end of the town of Stockport in Heaton-Norris parish, and from this last, a branch of 3 miles proceeds in a N.E. direction to Beat-Bank in Denton. The line has a rise of 152 feet between the *Rochdale* and *Huddersfield* canals. This canal is 33 feet wide at top, 15 feet at bottom, and 5 feet deep in water, except the summit pound which is made 6 feet deep to act as a reservoir; the locks are 80 feet long, and the boats carry 25 tons; there are three considerable aqueducts at Duckenfield, Ancoats, and at Water-Houses. This company were authorized by their first 4 acts to raise 170,000l., and a further sum by the late act; amount of shares 100l. The line of this canal was completed between Manchester and Ashton about the end of the year 1796, and in January 1797, the Stockport branch was opened; some of the works on this canal suffered by a flood in August 1799. The rates of tonnage are given in *Phillips's 4to. History, Appendix*, p. 21. In 1802, we were told, that the shares in this concern were 20l. below par.

MANCHESTER BOLTON AND BURY CANAL. Acts 31,

and 41 of Geo. III.—The general direction of this canal is N.W. for about 11 miles in the county of Lancashire; its northern end is considerably elevated; its objects are a communication between the great manufacturing towns of Manchester, Bolton, and Bury, and the carriage of coals and other articles for their supply, and forming part of the line of communication between Manchester and the *Leeds and Liverpool* canal. Manchester is the 2d British town with 84,020 inhabitants, Bolton is the 32d with 12,592 persons, and Bury the 84th with 7,072 persons. This canal commences in the *Mersey and Irwell* navigation near the junction of Medlock brook (by which it communicates with *Bridge-water's* canal near the beginning of the *Rochdale*) at Manchester, and terminates at the town of Bolton; it has a branch of 4 miles in length to the *Hoffenden* canal at the town of Bury. From the *Mersey and Irwell* navigation, is a rise of several locks to the basin in Salford parish; thence for about 4 miles is level; in the next 3 miles are 12 locks, the remainder of the line is level, including the branch to Bury; the whole rise is 187 feet. Previous to 1794, this canal was begun, and several locks were built for narrow boats, but on account of the branches connecting with wide canals which were proposed about that time, these were pulled up and rebuilt, and the canal widened, including some expensive deep-cutting and embanking; a want of skill or care appeared also, we are told, in the setting out of this canal by cutting deep through rocky ground which might have been avoided. There are two aqueduct bridges over the Irwell at Clifton-Hall and near Stocks, and one over the Leven at Long-fold, these are said to be 20, 16, and 10 yards high; the canal was, in 1799, supplied by a feeder from the Irwell at Bury, but in 1802, a reservoir and feeder also was found necessary in Radcliffe parish. In 1797, this canal was completed to Bolton, except the locks to connect with the *Mersey and Irwell* navigation; on the 17th of August, 1799, a great flood happened, which carried away the lower bank of this canal for 100 yards together on the summit-level, and another breach therein also happened, by which the navigation to Bolton, &c. was some time interrupted. This company were authorized by their first act to raise 97,000*l.*, and a further sum by the late act. The rates of tonnage are for coals, lime-stone, stone, bricks, clay, &c. 2d. per ton per mile, if they pass a lock; but all these, except lime-stone, are to pass on the levels for $\frac{1}{2}$ d. per ton per mile; and when the water runs waste at the locks, lime-stone is also to pay only $\frac{1}{2}$ d. on any part; the tonnage at the entrance of the *Mersey and Irwell* navigation is also regulated by the first act. Passage-boats from Bolton to near Manchester are established; but when water has been scarce, the passengers have been required to walk past the locks to another boat on the lower pound to avoid the waste of lockage-water. About the year 1794, it was in contemplation to make a branch westward from Bolton, to connect with the *Leeds and Liverpool* canal at Red Moss near to Wigan, and to make a grand extension of the Bury branch eastward to the *Calder and Hebble* navigation at Sowerby-bridge, passing the grand-ridge between Littleborough and Rippondale by a tunnel of 5 miles in length! after passing a shorter tunnel of $\frac{1}{2}$ a mile at lower Lomax near Heyford. In 1796, it was proposed to extend a branch from the basin in Salford parish to Oldfield-Lane in that town; and, in 1799, it was in contemplation to build an aqueduct bridge over the Irwell, and connect this canal with *Bridge-water's* canal, instead of locking down into the *Mersey and Irwell* navigation.

MARKET-WEIGHTON CANAL. Act 12 Geo. III.—The general direction of this canal is nearly N. for about 11 miles in the East Riding of Yorkshire; it has but little elevation

above the sea; its objects are the conveyance of coals, deals, &c. to Market-Weighton and the surrounding country, the export of farming products, and the better drainage of the fen lands through which it passes; it commences in the tide-way in the *Humber* river (opposite to the *Trent* river) at Fofdyke-Clough, and terminates near Market-Weighton. It has a sea-lock next the *Humber*, from whence it is level to within a short distance of its northern end, where is a rise of 4 or 5 locks. Mr. *John Smeaton* was consulted on this line of canal and drainage, in 1767, at which time a branch of this canal to Pocklington was in contemplation; for the rates of tonnage, see *Phillips's* 4to. *History*, p. 270. This navigation was completed soon after the passing of the act.

Mawgan Canal. About the year 1775, a narrow canal was cut of 6 or 7 miles in length: from Port Mawgan near Trenance on the N.W. coast of Cornwall, to within 3 miles of St. Columb Major, it was intended for bringing up coals and sea-land for manure, and for carrying down china-stone and clay, substances found in St. Dennis and St. Stephens, and used in the Staffordshire potteries; but after several of the adventurers were ruined, the scheme was totally abandoned.

MEDINA RIVER. The direction of this navigation is south, and nearly straight for $4\frac{1}{2}$ miles, in the Isle of Wight in Hampshire; the tide flows through its whole length; its object is the supply of Newport and the central parts of the island with coals and other articles; it commences at Cowes harbour (opposite *Southampton Water*), and terminates at Newport bridge.

MEDWAY RIVER (lower district.) Acts 32 and 42 of Geo. III.—The general direction of this navigation is nearly S.W. for about 27 miles by a bending course in the county of Kent; it is but little elevated in any part; its objects are the import of coals, deals, and other articles, and the export of Kentish-Rag lime-stone, fullers-earth, farming-produce, &c. near its northern termination, it connects with the east Swale or tide-way passage, of about 15 miles in length south of Sheppy island, connecting with the *Thames* near Whitstable; and, at Nicholson's ship-yard in Strood it is joined by the *Thames and Medway* canal. Chatham is the 46th British town with a population of 10,505 persons, Maidstone is the 66th with 8,027 persons, and Rochester is the 90th with 6,817 persons, Sheerness, Queenborough, and Milton, are considerable towns on or near this navigation, which commences in the river *Thames* at the Nore, and terminates in the upper *Medway* navigation at Maidstone bridge. Over this river at Rochester, there is a stone bridge of 11 arches and 550 feet long. At Chatham is a very considerable naval arsenal. The powers of the above acts for repairing and levying of tolls, extend no further down this river than from Maidstone to the tide-way at Aylresford bridge.

MEDWAY RIVER (upper district.) The general direction of this part of the river is S.W. for about 12 miles in the county of Kent; it is not much elevated in any part; its objects are the import of coals, deals, &c. and export of lime-stone, fullers-earth, farming-produce, &c. besides Maidstone, mentioned above, Tunbridge is the only considerable town on this line; it commences in the lower *Medway* navigation and terminates at the town of Tunbridge. In 1802, the *Medway and Rother* canal was proposed to connect with this river at Yalden-lees.

Medway and Rother. In the year 1801, a survey and estimate was made by Mr. *Sutherland*, for a canal from the *Rother* river intended navigable branch at Small-Hithe, to the *Stour* river at Canterbury (at the S. end of the proposed *Canterbury and Nicholas-bay* canal), with a branch thereof

to the *Medway* river at Yalden-lees, through the counties of Suffex and Kent; its objects were the supply of the interior country with coals and other articles, the export of timber and farming products, and forming a communication between the south coast at *Rye-harbour* and the *Thames* river, &c. Forty-ton boats were intended to be used, and the canal to be 4 feet deep. The summit was found to be about 100 feet above the sea, and nearly 50 miles of the line was to be upon one level.

MENAI STREIGHT. This freight separates Anglesea isle from North Wales, and has nearly a N.E. direction for about 16 miles, through which the tide flows; it extends from Caernarvon bay at Abermenai Ferry to Lavan Sands; Caernarvon and Bangor are considerable towns on this line. In 1801, and 1802, it was in contemplation to build a cast-iron bridge over this freight at Swelly rocks near Porthac-thavy Ferry not far from Bangor.

MERSEY AND IRWELL NAVIGATION. Acts 7 Geo. I. and 34 Geo. III.—The general direction of this navigation is nearly east, by a crooked course of 50 miles in the county of Lancaster, and skirting the county of Chester; the first 20 miles being by a most spacious estuary of the *Mersey* river; it is not greatly elevated in any part; its objects are most important, particularly in the immense trade between Liverpool and Manchester, and Hull, also by four different routes across the grand-ridge; the navigations immediately connecting therewith are, at Ellesmere-port in Netherpool, where it is joined by the *Ellesmere* canal; at Welton by the *Weaver* river; at Runcorn-Gap, and again at Manchester (by the Medlock Brook), by *Bridgewater's* canal, besides being crossed thereby on Barton aqueduct; at Fiddlers-ferry, and also at Sankey Brook, by the *Sankey* canal; and at Manchester, near the junction of Medlock Brook, by the *Manchester Bolton and Bury* canal; besides which, the following commence very near to this navigation, although they do not actually lock down into it: viz. the *Leeds and Liverpool*, at the basin in Liverpool, the *Trent and Mersey*, at Preston Brook, and the *Rochdale*, at Mancheller; to which also the *Manchester Ashton and Oldham* ought to be added, although a very short space of two other navigations must be passed through before you can reach the Irwell therefrom. Manchester is the 2d British town, with a population of 84,020 persons; Liverpool is the 4th, with 77,653 persons; and Warrington is the 45th, with 10,567 persons. This navigation commences in the Irish Sea, at Wallasey, about 3 miles below Liverpool, and terminates at the bridge between Manchester and Salford: but the powers of the act, as to improving the river and collecting the tolls, at first extended no lower than Bank-key, near Warrington, and since to Runcorn Gap. The winding course of the river has been shortened in several places by side-cuts across the loops, and locks and weirs have been erected in several places, the rise in the whole length being about 70 feet; these rivers are subject to sudden and violent floods, which have at times destroyed several of the navigation works; in August 1804 a new side-cut was completed, for shortening the course of the navigation, and avoiding the shallows in the river; between Warrington and Runcorn Gap it crosses the *Sankey* canal. The famous wet-docks at Liverpool are an appendage to the *Mersey* navigation, and are indeed a part of that river, from not being excavated in solid ground, where houses formerly stood, as they did on the site of the *London Docks*; but all of them, except the old Dock, which was a natural creek or pool, have been formed in the front of the town, by embankments in the river, which is here $\frac{1}{4}$ of a mile wide. At the lower or northern end of these docks, as we viewed them in 1797, is a large inlet or walled tide-basoon, which connects with the

river, and is dry at low water, from the S.E. corner of this is the entrance of *St. George's Dock*, which was the third large dock that was made, and is nearly a parallelogram, of 250 yards long and 100 wide, its quay being 670 yards long, its gates are 25 feet high and 38 feet wide, and it cost about 21,000 l. Passing southerly, we next arrive at a dry basin and wharf, called the old quay, for the flats or vessels belonging to the *Mersey and Irwell* company, which are about 32 in number; and some distance south of this is another large inlet to a spacious dry basin for ships: from the north end of this basin are other gates into *St. George's Dock*, above mentioned, and straight forwards is the entrance to the *Old Dock*, or the first that was built, and is wholly within the town; this dock forms an irregular parallelogram, of 200 yards long and about 80 yards wide, its gates being 23 feet high and 34 feet wide; it is lined with bricks, but all the other dock, basin, and pier walls are of beautiful hewn stone. From the south-east corner of the last described dry-basin is the entrance to *Salt-House Dock*, which was the second made, is an irregular trapezium, of 21,928 yards in area, and has 640 yards in length of quay, its gates being 23 feet high and 34 feet wide. A considerable distance south of the last dry-basin is an inlet to a small wet-dock which belonged to the late duke of Bridgewater, and is used by the flats which trade between Manchester and Liverpool, by *Bridgewater's* canal, these carry 50 tons, and 42 of them belonged to his grace. Proceeding further along the shore southward, we arrive at another inlet and dry-basin, from the north side of which is the entrance to the *King's Dock*, the fourth which was made (being finished in 1788), and is a regular parallelogram, of 290 yards long and 90 wide, the gates thereof being 25 feet high and 42 feet wide. From the head, or east end of the last dry-basin is the entrance to the *Queen's Dock*, which was the fifth and last that was made, being also the largest and most complete of the whole, its length is 270 yards, breadth 150, its gates 25 feet high and 42 feet wide, and it cost about 25,000 l. An attempt was made to form a dock in the site of the *old Dock*, as long ago as 1561, but it was not until the year 1710 that the first act was obtained, of which there are several, for building and regulating the present docks. In 1799 application was made again to parliament for powers to build two more large docks, one of them more northerly than any of those we have described, and the other in front of *Salt House* dock. The whole extent of these docks and quays will then be nearly 2 miles by the side of the *Mersey*! With the two dry basins last described, several convenient graving-docks connect, for the building or repair of ships, some of the latter are long enough to hold three ships in length. The space between these graving-docks and in front of the docks, is principally occupied by timber-yards. The draw-bridges over the entrances to some of these docks are among the largest and most complete in England: Mr. Morris erected and has the care of them and the docks. On the south side of the *King's Dock* is a spacious warehouse 210 feet long and 180 wide, for tobacco, of which it will contain 7000 hogheads. The spring-tides here rise 21 feet, but the neap-tides only 12 feet, on which account large ships cannot enter or leave these docks for some days during the lowest tides. Fires and smoking of tobacco are on no account allowed on board of ships in these docks, nor lighted candles, except in proper lanterns, and no gunpowder is allowed on board; by a strict attention to which rules, no fire has ever happened in these docks. In the year 1797 the tolls in these docks amounted to upwards of 13,300 l. annually, and their yearly expences to 5,100 l. but a debt of 113,419 l. still remained on them: for many of the above particulars we are indebted to *W. Moss's Liverpool Guide*. In the year 1737

Worsley Brook was intended (and an act passed 10 Geo. II.) to be made navigable; and, in 1758, a branch of *Bridgewater's* canal was intended to join at Hollin Ferry, but neither of these has been executed. In 1771 Mr. *James Brindley* proposed an aqueduct-bridge over the estuary of the *Mersey* river, for the use of the intended *Liverpool and Runcorn* canal; and in 1801 Mr. *Ralph Dodd* tried to persuade the adoption of a road-bridge over the same at Castle Rock near this place, 412 yards long, which he stated might be built for 47,000*l.* In 1799 it was suggested that a tunnel might be made under the *Mersey* at Liverpool to the opposite shore in Cheshire, $\frac{3}{4}$ of a mile; in the same year it was in contemplation to build an aqueduct over the *Irwell*, for the use of the *Manchester Bolton and Bury* canal, to enable it to join *Bridgewater's* canal; and in 1804 it was proposed to bring the *Weaver* navigation to Weston Point on this navigation, by a new side-cut, near that river from Frodsham, to avoid the shallows near the junction of the rivers. In 1758 the price of carriage on this navigation, between Liverpool and Manchester was 12*s.* per ton, but on the completion of *Bridgewater's* canal it fell to 6*s.* per ton.

MILFORD HAVEN. This famous estuary and harbour for large ships, has nearly an east course, for about 17 miles, in the county of Pembroke, in South Wales, commencing in St. George's channel, and terminating near Landshipping ferry, where it is joined by the *Douglidge* and *Clelby* rivers: it has also creeks or branches extending to Pembroke, to near Carew Castle, to Cresswell, to Nangle, &c.

MONKLAND CANAL. The general direction of this canal is nearly east, for about 11 $\frac{1}{2}$ miles in the county of Lanerk in Scotland, its eastern end is considerably elevated; its objects are the supply of Glasgow, Paisley, &c. with coals from Monkland collieries, and the export of farming products. It commences in the basin of the branch of the *Forth and Clyde* canal, and thereby communicates with the *Clyde* river, and the *Edinburgh and Glasgow* canal. Glasgow is the 5th British town, with a population of 77,385 persons. In 1803 the *Glasgow and Saltcoats* canal was proposed to connect with this at Glasgow.

MONMOUTHSHIRE CANAL. Acts 32, 37, and 42 of Geo. III.—The general direction of this compound of canals and rail-ways is nearly north, for 17 $\frac{3}{4}$ miles, in the counties of Monmouth, and Brecknock in South Wales; its northern ends are very greatly elevated; its object is the export of coals, lime, and iron from the country through which it passes; near Pontypool it is joined by the *Brecknock and Abergavenny* canal, at Pill-Gwenlly it joins to the *Sirhowy* tram-road (by means of the *Ufke* river), and at Count-y-Billa farm, and at Risca, it joins the same again by different branches belonging to this company. Newport and Pontypool are considerable towns on this line. This canal commences in the tide-way of the *Ufke* river, near to the *Severn*, at Pill-Gwenlly, and terminates by a rail-way extension at Blaen-Afon iron furnaces, having also a principal branch of canal from the line at Crynda-Farm, near Malpas, and continued by a rail-way to Beaufort iron-works, 21 miles: from this branch are rail-way branches to Sorwy furnace, 1 $\frac{1}{2}$ mile, to Nant-y-glo works, 6 $\frac{1}{2}$ miles, and another to the *Sirhowy* tram-road at Risca: from the line near Pontypool is a rail-way branch, 1 mile, to Tronsmant furnace, and another, of $\frac{1}{2}$ a mile, to Blaen-Dir furnace. From the *Ufke* river to Pont-Newydd, 12 $\frac{1}{2}$ miles, is a rise of 447 feet by the canal, and thence to Blaen-Afon, 5 $\frac{1}{2}$ miles, is a rise of 610 feet by the rail-way: from Crynda-Farm to Crumlin bridge the canal branch rises 358 feet in 11 miles; thence for 3 miles to the rail-way bridge over Ebwy river, 3 miles, the rail-way has a rise of 139 feet, and thence to Beaufort, 7 miles, it has a rise

of 480 feet; the Nant-y-glo branch has a rise of 518 feet, along the side of Ebwy-Trach river. The locks are 60 feet long and 10 feet wide, their paddle-holes are, in some of them, united in the breast of the lock, and no sheet-piling, or inverted arch has been made below the lower gates. Much deep-cutting and embankments have here been necessary, to obtain the proper slopes for the rail-ways and inclined planes. Mr. *Thomas Dadford jun.* is the engineer: in February 1796 the canal was completed from the *Ufke* to Pontypool, and in the same year the Beaufort branch was completed. This company were authorised by their different acts to raise 275,330*l.* in 100*l.* shares: in 1802 these divided 2*l.* 12*s.* 6*d.* each annually; it is provided, that after the profits amount to 10 per cent. and 1000*l.* is accumulated as a fund, the tolls are to be reduced, first on coals, so as to keep the profits within that amount. The tolls and exemptions are various, and may be consulted in *Phillips's 4to. History, Appendix*, p. 18 and 19, where tolls are specified for cattle passing on the rail-ways. Nine miles of the *Sirhowy* tram-road was made by this company, who receive the tolls thereof, as also 110*l.* per annum from that company, on account of the junctions therewith: to the *Brecknock and Abergavenny* company this company paid the sum of 3000*l.* for the benefit of their junction herewith, and their taking the same tolls only on goods passing on it from this canal as are charged hereon. Rail-way branches may be made to any works within 8 miles of this canal or its branches. In the year 1805 it was proposed to continue this canal lower down the *Ufke* river, to avoid its imperfect navigation.

MONTGOMERYSHIRE CANAL. Act 34 Geo. III.—The general direction of this canal is nearly S.W. for 27 miles in the county of Salop and of Montgomery in North Wales; it is considerably elevated, particularly its southern end; its objects are the supply of the country with lime, the export of its farming products and of coals, slate, free-stone, iron, lead, &c. from different parts near the line: it connects with the *Severn* river at Welshpool. Welshpool, Montgomery, and Newton are considerable towns on or near this canal: it commences in the Llanymynach branch of *Ellefmere* canal, at Portyvain lime-works in Llanyblodwell, and uniting with the same again near Verniew river in Llanymynach, it terminates at Newtown: it has a cut of 3 $\frac{1}{2}$ miles to the *Severn* river at Welshpool and to Guilsfield. From the *Ellefmere* branch to Newtown is a lockage of 225 feet: the Guilsfield cut is level. Mr. *Thomas Dadford jun.* is the engineer. In August 1797, 16 miles of the canal were finished and opened from the *Ellefmere* branch to Garthmill near Berriew. The company were authorised to raise 92,000*l.*; the amount of each share 100*l.* The water of Lledan Brook is to be taken to supply this canal for 24 hours weekly, from Saturday to Sunday evening; the company are bound to purchase certain mills, if their trade is injured by the canal: and certain creditors on turnpike tolls near the canal are also indemnified: the profits are not to exceed 10 per cent. but the tonnage is to be reduced, but not so as to bring the profits below 8 per cent.: the rates of tonnage and exemptions are various: see *Phillips's 4to. History, Appendix*, p. 151 and 152. About the year 1794 the *Welshpool and Leominster* canal was proposed to join this near Welshpool.

NEATH CANAL. Acts 31 and 38 Geo. III.—The general direction of this canal is nearly N.W. for about 14 miles in the county of Glamorgan in South Wales; and its northern end is considerably elevated; its object is the export of coals, iron, lime-stone, &c. from the mines and works near the line; which commences in the tide-way of the *Neath* river, at Giants-grave pill in Briton's-Ferry, and terminates in the *Aberdare* rail-way branch at Abernant near Furno

Vaughan: being joined near Briton's Ferry, in the *Neath* river, by the *New Chapel* canal. Neath is the only considerable town on this line; near Merliu's Court is an aqueduct over the Neath river. This company were authorised to raise 35,000*l.*; they are authorised to make rail way branches to any place within 4 miles of the line, by consent of the land-owners. In 1798 this canal was nearly finished, except about two miles at the lower end. Here is a singular provision, that the rates of warehouse-room are to be the same as are charged by the *Staffordshire and Worcester* company at the Stourport warehouses.

NEATH RIVER. The general direction of this navigation is nearly N. for about 4 miles in the county of Glamorgan, in South Wales: the tide flows through its whole length from Swansea bay to Neath bridge; at Giants grave pill near Briton's Ferry it is joined by the *Neath* canal, and near Briton's Ferry by the *New Chapel* canal; its chief objects are the supply and trade of Neath, and the export of the coals and iron brought down by the canals.

NEN RIVER (lower district.) Acts Geo. 11., and 34 of Geo. III.—The general direction of this navigation is about S.W. by a very crooked course of nearly 75 miles in the counties of Cambridge and Huntingdon, and skirting those of Lincoln and Northampton; this is by what appears to have been its ancient course through the Fens, beginning in the tide-way at Peter's point about 9 miles below Wisbeach, passing that town, where is a bridge built of stone with one flat semi-elliptic arch of 70 feet span; and turning south-eastward by an ancient course (which is now rendered useless to navigators by the *Wisbeach* canal, which joins this river at Wisbeach and again at Outwell), to Outwell and Apwell, thence to March and Eenwick, thence through Ramsey, Ugg, and Whittlesea Meers, through Horsey-bridge, and Standground sluice to Peterborough, and thence by the regular channel of this river to the commencement of the upper *Nen* navigation at Thrapston; in after times, a navigable course has been opened, for part of the waters of this river through Well-Creek, about 5 miles in length, from near Outwell-church to the Great *Ouse* river at Salter's-Load; another from Standground (1½ mile below Peterborough) through Catt-Water and Shire Drain of about 24 miles in length to the *Nen* river again at Gunthorpe-sluice (about 6½ miles below Wisbeach), this last having a cut of about 2 miles in length from it into the old *Welland* river near Crowland; in 1490, bishop Moreton cut a new straight course 40 feet wide and 13 miles long, called Moreton's *Leam*, for a part of these waters, from Standground sluice (about 2 miles below Peterborough) to near Guyhirne, and thence 3 miles by an old channel to the *Nen* again near Wisbeach; also, at Benwick this river is joined by the Benwick-Meere branch, of the Great *Ouse* river. The above will serve to give some idea of the principal lines of navigation belonging to this river through this surprizing country; but as all the rivers, and all drains almost in the fens are embanked on both sides, and owing to the deficiency of fall are almost still water, there are a great number of smaller navigable branches intersecting and crossing each other in all directions, so that it would be in vain for us to attempt to describe them. The powers of the commissioners under the above acts, extend only about 30 miles downwards to Peterborough bridge; the navigations through the fens are preferred by the fen corporation in maintaining their drainage works. In 1721, Mr. Nathaniel Kinderley recommended the cutting of a new channel or out-fall for this river (as has been since successively practised by him on the *Dee* river at Chester) from the mouth of Shire-drain at Gunthorpe-sluice straight along the N.W. shore for 2 miles to Peter's point; and the work was begun, but the

mistaken notions of the people of Wisbeach then, and till lately, prevented its completion: we are glad, however, to hear, that the same is likely now to be soon accomplished, and a greater depth of water obtained in this river, and through Cross-keys wash to Lynn and Boston deeps. By the act for *Wisbeach* canal 34 Geo. III., all vessels passing out of or into that canal from the *Nen* are to pay 3*d.* per ton, out of which 100*l.* is to be paid annually to the commissioners under the above acts for improving this river above Peterborough, and the remainder is to be applied to deepening and improving the same between the *Wisbeach* canal at Outwell and the *Ouse* river at Salters-Load. Boats which have paid the above toll are to pass toll free at Salters Load, and Standground sluices on this river.

NEN RIVER, (upper district.) The general direction of this navigation is nearly S.W. for about 23 miles, in Northamptonshire: it is not greatly elevated; its objects are the supply of Northampton and the surrounding country with coals, deals, &c. and the export of agricultural productions. The communication between Lynn, London, Liverpool, Manchester, &c. which it now effects is also important. Northampton is the 85th British town with a population of 7,020 persons, Wellingborough, Thrapston, and Higham-Ferrers, are also considerable towns on or near this river; it commences in the lower *Nen* navigation at Thrapston, and terminates at the rail-way branch of the *Grand Junction* canal at the town of Northampton, where also it is to be joined by the *Leicestershire and Northamptonshire Union* canal. This navigation has been improved by a great number of side-cuts and pound-locks by the side of the river in different places; it was completed and opened to Northampton on the 7th of August 1761. About the year 1793, the *Leicester and London* canal was proposed to cross this river near Wellingborough.

Newark and Bottesford. In the year 1793, a canal was intended from the *Dean* river at Newark to the long level of the *Grantham* canal at Stainwith, passing near the town of Bottesford. In the *Grantham*, act 33 Geo. III., the tolls are provided that are to be paid at the junction of these canals, if this is ever executed.

Newcastle and Carlisle. In the year 1795, Mr William Chapman surveyed the line for a canal from the *Tyne* river at Newcastle to the *Eden* river at Carlisle, through Durham, Northumberland, and Cumberland, crossing the grand-ridge for a connection between the east and west seas; and having a collateral branch of narrow canal and inclined-planes to the elevated mining districts of Weardale and Teesdale forests, &c. the estimate being 355,067*l.* On the rejection or suspension of this scheme, a canal from *Newcastle* to *Haydon-bridge* was proposed as below.

Newcastle and Haydon-Bridge. In 1796, and again in March 1802, it was in contemplation to make a canal nearly following the course of the *Tyne* river, between Newcastle and Haydon, in Northumberland and Durham.

Newcastle and Maryport. Some years previous to 1801, a canal was projected between the tide-way in Maryport harbour and the *Tyne* river at Newcastle, crossing the grand ridge, and passing between the two seas, though Cumberland and Durham counties: a bill for the same was brought into parliament, but rejected, owing to the opposition that the favourers of another scheme gave to it: in 1801, the scheme was again revived, but nothing effectual has been done towards its adoption.

NEWCASTLE (under-line) CANAL. Act 35 Geo. III.—The general direction of this navigation is nearly west, by a very bending course of 3 miles, in the county of Stafford: its objects are the bringing of Caldon lime for manure,

and the export of coals and farming products: it is considerably elevated. Newcastle is a considerable town, and its neighbourhood very populous. This canal commences in the *Trent and Mersey* canal (near to the end of the Caldron branch) at Quinton's Wood, in Stoke, and terminates in the *Newcastle under-line Junction*, at the south-east corner of Newcastle town. It was completed in a short time after the act was obtained, the company being authorised to raise 10,000*l.*; the amount of shares therein is only 50*l.* each. The rates of tonnage and wharfage are on coals, lime-stone, and iron-stone 1*½d.* per ton per mile, on all other goods 2*d.* per ton per mile, but for less than a ton of any article in a boat 6*d.* Between December and the 1st of April this company may take flood waters from the Trent river.

NEWCASTLE (under-line) JUNCTION CANAL Act 38 Geo. III.—The general direction of this canal is about N.W. for a short distance, in two detached parts, in the county of Stafford: its western ends are much elevated, and terminate near the grand ridge on its eastern side: its object is the export of coals and agricultural produce. Newcastle is a considerable town on its line. It commences in the *Newcastle-under-line* canal, at the S. E. corner of that town, and terminates its eastern part in the canal of Sir *Nigel Bowyer Gresley*, near the S.W. corner of the town; its western part commences in *Gresley's* canal above mentioned, near *Apedale*, and extends to *Partridge-Nest* collieries, with a branch to *Bignel-End* collieries. This company were authorised to raise 12,000*l.*, the amount of their shares being 50*l.* only: provision is made in the act for inclined-planes and water-levels, or rail-ways, with engines to raise water or draw trams, &c. in case any of these should be found more eligible than a canal with locks, in any part. Pleasure boats to pay for 6 tons if they pass any lock. In 1796, the *Commercial* canal, for 40 ton boats, between the *Ashby* and *Chester* canals, was proposed to occupy or pass through the line of this canal, when enlarged.

NEW CHAPEL CANAL. The general direction of this canal is east, by a bending course of about 3½ miles, in the county of Glamorgan, in South Wales; the greater part of it is cut through a morass, but little above the level of the tide-way in which it commences, in the river *Neath*, near *Briton's Ferry* (near the entrance of the *Neath* canal), and terminates at *New Chapel*, near *Swanley*: it is the sole property of the owner of the land, and for whose improvement, by draining and otherwise, it was principally undertaken.

Newport and Stone. In June 1797, it was proposed to make a canal from the *Donnington Wood* canal (the marquis of *Stafford's*) at *Pave-lane*, near *Newport*, by *Eccleshall*, to the *Trent and Mersey* canal, near *Stone*, a course of about 18 miles, in the counties of *Salop* and *Stafford*, crossing the grand-ridge; a branch was proposed to *Market-Drayton*: its object was the opening of a direct communication between *Shrewsbury*, and other places on or near the upper parts of the *Severn*, and the *Trent and Mersey* canal, for supplying the intermediate country with coals and lime, &c. In 1795, the *Tern-bridge* and *Winsford* canal was proposed, and intended to pass through nearly the same ground as the middle parts of this canal; as was also the *Sandbach* on an other occasion.

NEWRY CANAL (Ireland). This canal, from the tide-way at *Fadham* point to the town of *Newry*, was completed under the direction of Mr. *Golborne*, in February 1761, after being two years in hand, by which brigs of 80 or 100 tons burthen can come up to *Newry*; it was intended to extend this to the *Blackwater* navigation, for conveying the *Dunannon* and *Drumgals* coals to *Dublin*; and the Irish parliament, between 1753 and 1771, granted different sums of

the public money for this purpose, amounting to 11,434*l.* but the work then was far from being completed.

NITH RIVER. The course of this river (sometimes called the *Nid*) is nearly north for about 9 miles, between *Dumfries* and *Kirkcudbright* counties, in Scotland; the tide flows through its whole length, and its object is the supply of *Dumfries*, (the 75th British town, with 7,288 persons); it commences in *Solway Firth*, and terminates at *Dumfries* bridge, which is of stone, with 13 arches. In 1760, Mr. *John Smeaton* was consulted on the encroachments by jetties of flakes and stones for gaining land, that had been made at *Cargin*, *Lagal*, and *Netherwood*, on this river, and recommended the removal of some of these works at the projecting points of the river.

NOTTINGHAM CANAL. Act Geo. III.—The general direction of this canal is nearly N.W. by a crooked course of about 15 miles, in the county of Nottingham; it is not very greatly elevated: its objects are the export of coals from the several mines near it, and of farming products, importing lime, deals, &c. Nottingham is the 17th British town, with a population of 28,861 persons. This canal commences in the river *Trent*, near Nottingham (opposite to the junction of the *Grantham* canal), and terminates in the *Comfort* canal, near *Langley* bridge, and near to the termination of the *Erewash* canal: near to its southern termination it is joined by the *Trent* canal or side-cut (from the *Trent and Mersey* canal). A reservoir is made near *Amfworth* for the supply of this canal, and has a self-regulating sluice which lets out near 3000 cubic feet of water per hour for certain mills and the *Erewash* canal. In 1802, this canal was completed.

NUTBROOK CANAL. Act 33 Geo. III.—The general direction of this canal is nearly N.W. for 5 miles, in the county of Derby: it is not greatly elevated: its object is the export of coals from the mines near the line; which commences in the *Erewash* canal, near *Stanton*, and terminates at *Shipley* colliery; it has a branch to *West Hallam* collieries. Sir *Henry Hunloke* and *Edward Miller Mundy*, esq. were authorised to raise 19,500*l.* between themselves, in 100*l.* shares; their profits hereon are not to exceed 8 per cent.; and proprietors of adjoining lands may make side branches thereto: the particulars of the tonnage rates are very long, including some regulations with the *Erewash* company, &c. See *Phillips's* 4to. *History, Appendix*, p. 104 and 105.

OAKHAM CANAL. Acts 33 and 40 Geo. III.—The general direction of this canal is about S.E., by a crooked course of 15 miles, in the counties of *Leicester* and *Rutland*: its southern end is considerably elevated, crossing the *Tilton* and *Burley* branch from the grand-ridge: its objects are the supply of *Oakham*, and the country through which it passes, with coals, deals, &c., and the export of agricultural products. *Oakham* and *Melton-Mowbray* are considerable towns on this line, which commences in the *Leicester and Melton-Mowbray* navigation, at *Melton-Mowbray*, and terminates at the town of *Oakham*. From the *Leicester and Melton-Mowbray* navigation to *Edmondthorpe*, 8½ miles, it has a rise of 126 feet; the remaining 6½ miles to *Oakham* are level, and it is fed by a reservoir for flood-waters in *Langham*, and another in *Saxby*. The engineers were Mr. *William Jessop* and Mr. *C. Staveland*, jun. In November 1800, this canal was opened from *Melton-Mowbray* to *Saxby* bridge, and in January 1803, the whole was completed. This company was authorised to raise 86,000*l.* in 100*l.* shares. The rates of tonnage and wharfage, with the exceptions therefrom, may be seen in *Phillips's* 4to. *History, Appendix*, p. 106 and 107, but to which the last act made an addition,

and the *Lepinger and Melton-Mowbray* act, 40 Geo. III., also contains some regulations affecting the tolls at the entrance to this canal. Earl Winchelsea is to be paid 15l. annually, in lieu of his customary dues on coals sold in Oakham town.

OUSE RIVER (Lewes lower Navigation). Act 31 Geo. III. The general direction of this navigation is nearly north, for near 9 miles, in the county of Sussex: the tide flows through its whole length: its objects are the import of coals, deals, &c. and the export of farming products. Lewes is a considerable town on this navigation; which commences in the English channel, at Newhaven harbour, and terminates in the upper *Ouse* navigation, at Lewes bridge: the meadows, called Lewes and Laughton Levels, near this river, were subject to be overflowed, and it is part of the object of the above act to embank the river and its tributary streams, and to erect proper sluices, and cut drains for the improvement thereof; part of the money for which draining purposes, is to be raised by the commissioners of sewers, under the act of 23 Hen. VIII., by different rates per acre on each of the five districts into which the levels are by this act divided, but the works are to be performed by the trustees appointed by this act, who, in 1802, completed the straightening and deepening of the course of the river, so that the tides flowed higher and ebbed lower than before at Lewes bridge, and to which place vessels drawing 4 feet of water can now come up. The tolls on articles navigated on any part of this river are to be, for manures not exceeding 2d. per ton, for road-materials 3d., and for all other goods 4d. per ton, empty boats to pass toll free; these tolls are not to be lowered (except road-materials to 2d.), so long as 6,000l. of the money borrowed on the credit of these tolls and the acre-taxes, remain undischarged; the tolls are intended hereafter to be so reduced, that one-third of the whole expences of maintaining the navigation and drainage works shall be paid by the acre-taxes, and two-thirds by the tolls on the river; the acre-tax is, however, to make up the deficiency, if the above tolls are inadequate; lands below Newhaven bridge are not to be taxed, but to maintain their own banks. In the year 1762, Mr. John Smeaton was consulted about improving the navigation and drainage of this river. About the year 1793, a new pier was built to protect the harbour of Newhaven, and the entrance of this river; in 1802, it was proposed to add a new groin thereto to the westward, for the further security of vessels; and, in 1804, it was in contemplation, by large stones from the neighbouring cliff, to extend a rough unvalled pier much further out into the sea, for the security of vessels on this coast.

OUSE RIVER. (Lewes upper Navigation). Act 30 Geo. III.—The general direction of this navigation is nearly north-west, by a bending course of about 22 miles, in the county of Sussex: it is not much elevated above the level of the sea: its objects are the import of coals, deals, &c. and carrying chalk and manures to the lands, and the export of their agricultural products. Lewes and Cuckfield are considerable towns on this line; it commences in the lower *Ouse* navigation, at Lewes bridge, and extends to Hammer bridge, near Slaugham, with a branch to Offham chalk-pit, in Hamfay; the depth of water in every part is to be made $3\frac{1}{2}$ feet: the boats to be 50 feet long and 12½ feet wide, and are not to pass locks with less than 10 tons of lading. This company were authorised to raise 25,000l. in 100l. shares, and the works were not to commence until 10,000l. of this was subscribed, and 10 per cent. thereon actually paid: it is to that public spirited and worthy nobleman lord *Sheffield* that the country are in a

principal degree indebted for bringing about this useful measure. From Lewes bridge to Barcombe mill there was an old and imperfect navigation for small boats; on this part of the line, the rates of tonnage are to be, on manures, road-materials, timber, grain, &c. ½d. per ton per mile, and on all other goods 1d. per ton per mile; on the remainder or new part of the line, manures, &c. 2s. above, are to pay 1d. and other goods 1½d. per ton per mile. Empty boats to pay 1s. for passing each lock, and pleasure boats 3d. below and 6d. above Freshfield bridge for passing locks. Between Old Eye, in South Malling, and Land-Port, no toll is to be taken, on goods carried no farther. Branches may be made to any place within 2000 yards of this river, on which the powers of the commissioners of sewers (13 Hen. VIII.) still continue. In 1801, it was proposed to make an extension of the *Swry iron railway* to join this navigation at Linfield. In 1802, the navigation was not completed up to Hammer bridge; but, in the following year, it was said that a new act for further powers for that purpose was in contemplation.

OUSE (great) RIVER. The general direction of this river is nearly S. W., by a crooked course of about 84 miles, in the counties of Norfolk, Cambridge, Huntingdon, and Bedford, and skirting Suffolk for a short distance: this course through the fens being from the tide-way in Lynn deeps, (3 miles below that town), past Lynn, Tolney, Salter's Load, Denver-sluice, Rebeck, Little port chair, Ely, Harriemere, Hermitage-sluice, Erith, and thence by the regular channel of this river to Bedford. Soon after the year 1630 (in consequence of a law of sewers of the 13th of January, 6 Charles I.) the old Bedford river, (a straight cut, of 21 miles long and 70 feet wide), was made, between Hermitage-sluice; and Salter's-Load, for conveying part of the waters of this river; and in 1652, the scheme of Sir *Cornelius Vermeyden* for another navigable cut nearly parallel to the last was carried into effect, (under the authority of an act of Cromwell, 1649, confirmed afterwards by 15 Charles II. establishing the fen corporation); this last, called the New Bedford river, is 20 miles long and 100 feet wide, from Hermitage sluices to Denver's sluice, both these new cuts falling into the great *Ouse* river again, at Salter's-Load and Denver's sluice (which are within about a mile of each other, and 17 miles from Lynn); besides these, part of the waters of this river make their way by a navigable cut of about 12 miles in length, from Hermitage into the *Arn* river at Benwick. In 1725, Mr. *Thomas Badstade* mentioned, and, in 1751, Mr. *Nathaniel Kinderley* strongly recommended, another shorter cut between Eaubrink and Lynn, for straightening the course of this river, for which the acts of the 35, 36, and 45 of Geo. III. have been passed, called the Eaubrink cut, and on which Mr. *Robert Mylne*, Sir *Thomas Hyde Page*, and captain *Joseph Huddan* are employed as engineers; this cut was, in September 1804, marked out, and is intended to be 266 feet wide at the east end, 204 feet at the west end, and about 2½ m's in length, making easy bends into the river at each end, with banks on each side, at a distance from the cut, 6 feet higher than the ordinary tides, of 15 feet rise, with an embankment and sluice across the old channel, above the east entrance of the new one; which important works ere long, we hope, will be completed. Near the harbour of Lynn this river is joined by the *Lynn* river; at Salter's-Load, by a branch of the *Nen* navigation (called Well Creek); between Salter's-Load and Denver's sluice it is joined by *Stoke* river; at Rebeck the little *Ouse* joins; at Prick willow the *Lark* river joins; near Barkway chapel the *Sobam-Lode*; at Harriemere, the *Cam* river joins; and at Tempsford the *Isel* river also joins: the whole of the rivers and large drains in

these fens being embanked and nearly level; there are many others of them navigable for short distances besides the above. Lynn is the 50th British town, with a population of 10,026 persons: Downham, Ely, St. Ives, Huntingdon, St. Neots, are also considerable towns on this line. Densers dam and sluice, with 5 eyes or arches, was built across the great *Ouse* river, just above the entrance of the new Bedford-river, in the year 1651; in 1713, the water having undermined three of the arches, they were carried away, and were not rebuilt again until 1746. At Willington and others of the mills in the upper parts of this navigation, there is a kind of self-acting sluices in use, which fall down to let the water pass freely over them, when the water in a flood rises above a certain height; the locks on this part of the navigation are of wood, the towing-path has stiles near it, and is frequently interrupted as before mentioned. In November 1796 a dry dock in Lynn, connecting with this river, was opened, being the first work of the kind which had been erected for the accommodation of that port. About the year 1780, a cut, of about $1\frac{1}{2}$ mile in length, was made from this river, in Willington, to the turnpike road in Cople, where a house and conveniences for a wharf were built (now the Dog-ale-house) at a great expence; but the consent of the proprietor of the *Ouse* navigation, who holds it under a particular grant from the crown, could not afterwards be obtained for this cut being used as a navigation. In 1785, and again in 1802, the *London Lynn and Norwich* canal was proposed to join this river at Lynn. And in 1792, the *Leicester and London* was proposed to join and cross it at Bedford.

OUSE (Little) RIVER. This river (often called the Brandon) has its course nearly east, for about 20 miles, between the counties of Norfolk and Suffolk: it is not greatly elevated in any part: its objects are the import of coals, deals, and the export of agricultural products. Brandon and Thetford are considerable towns on this river, which commences in the great *Ouse*, at Rebeck, and terminates at the town of Thetford, to which place boats with 14 or 15 chaldrons of coals in each could come up in the year 1649. The lower part of this river for several miles is embanked on both sides, through the fens. In the year 1789, this navigation was proposed to be joined at Hils near Wilton by the intended *Bishopstortford and Wilton* canal.

OUSE RIVER (York). Act 23 Henry VIII.—The general direction of this river is nearly north-west for about 48 miles, between the East, West, and North Ridings and Ainsty Liberty in Yorkshire; it is not very greatly elevated in any part; its objects are the trade and supply of the city of York, and of the immensely populous and trading districts in the West Riding. At Gooie-bridge it is joined by the *Don* river; at Armyn, by the *Ayre and Calder* navigation; at Barnby, by the *Derwent* river; at Selby, by a cut of the *Ayre and Calder* navigation; near Cawood, by the *Wharfe* river; and at York, by the *Foss* river. York is the 23d British town, with a population of 16,145 persons. Howden, Snaith, Selby, and Cawood are also considerable places on or near this river; which commences in the *Humber* river at Trent-fall (the junction of the *Trent* river) to the *Tore* river at Linton. Ships of 150 or 160 tons burthen come up to Armyn, and smaller masted vessels to York city. By a licence of Richard II. the corporation of York are required to maintain certain bridges on the upper part of this river. In the year 1795, a large wooden draw-bridge, of 13 openings, was built by Mr. William Jessop over this river at Selby, under an act of parliament. In 1769, the *Selby and Leeds* canal was proposed to connect with this river at Selby.

OXFORD CANAL. Acts 9, 15, 26, 34, and 39 of Geo. III.—The general direction of this canal is nearly north, by a very crooked course in its northern half, of 91 miles, in the counties of Oxford, Warwick, and Northampton; it crosses the grand-ridge by a tunnel, and its northern part skirts along near to it on the western side for many miles; its objects were a communication between the midland canals and the metropolis, (but a much nearer route is now opened by the *Grand Junction* canal,) the supply of the northern parts of Oxfordshire with coals, the export of farming products, &c. At Woolvercot is a cut of about $\frac{1}{4}$ mile (belonging to the duke of Marlborough), by which a communication with the *Thames and Isis* navigation at Godstow is effected. At Napton the *Warwick and Napton* canal joins this; and at Braunton the *Grand Junction* canal joins. Coventry is the 24th British town, with a population of 16,034 persons; and Oxford is the 38th, with 11,694 persons. Woodstock, Deddington, Banbury, Southam, Daventry, and Rugby are also considerable towns on or near to this line of canal; which commences in the *Thames and Isis* navigation at Badcock's Garden on the west side of Oxford city, and terminates in the *Coventry* canal at Longford. At Hillmorton and at Napton are short cuts, of about $\frac{1}{2}$ a mile each, to the steam-engines belonging to this company. From the *Thames and Isis* at Oxford to Banbury, 27 $\frac{1}{4}$ miles, is a rise of 118 feet by 18 locks (including 2 weir-locks and an entrance lock from the Isis); thence to Claydon, 7 $\frac{1}{2}$ miles, is a rise of 77 $\frac{1}{2}$ feet by 12 locks; thence (through the Fenny-Compton tunnel) the summit pound continues to Marston-doles wharf 10 $\frac{3}{4}$ miles, and level; thence to Napton on the hill 2 miles, is a fall of 55 $\frac{1}{2}$ feet by 9 locks; thence to Hillmorton, 16 $\frac{3}{4}$ miles (in which the *Warwick and Napton* and the *Grand Junction* join), is level; thence in $\frac{1}{2}$ a mile is a fall of 19 feet by 3 locks; thence to the *Coventry* canal at Longford, 26 $\frac{1}{2}$ miles, is level. The two short cuts to the engines, and that at Woolvercot, are level. This canal is 28 feet wide at top, 16 feet at bottom, and 4 $\frac{1}{2}$ feet deep, except the summit pound, which is made 6 feet deep in order to act as a reservoir; the locks are 74 $\frac{3}{4}$ feet long, and 7 feet wide. At the toll-house near Longford is a stop-lock, to prevent the *Coventry* canal in dry seasons, from lowering the water in the long pound on this; from which long pound an engine at Hillmorton pumps water into the Braunton pound, by means of a feeder; and out of this last pound by means of a lough. Another engine at Napton pumps into the summit pound, which is also fed by three reservoirs. The number of stone and brick bridges on this line is 188, and of wooden, swing, draw, and foot bridges 66. The Fenny-Compton tunnel is 1188 yards long, 9 $\frac{1}{2}$ feet wide, and 15 $\frac{1}{2}$ feet high. At Newbold is a tunnel 125 yards long, made under the church-yard and street, 16 feet high, and 12 $\frac{1}{2}$ feet wide, with a towing-path through it. At Wolfhamcote, also, there is a short tunnel. At Pedlars-bridge near Brinklow is an aqueduct bridge of 12 arches, of 22 feet span each. At Cosford on the *Swift* river, and at Clifton on the *Avon*, are others of 2 arches each; at Wolfhamcote, Adderbury, and Hampton-Gay, are other smaller aqueducts. Mr. James Brindley made the survey for this canal in September 1768; in August 1769 he began the work near Longford; and in 1775 it was completed from thence to the Napton locks; when 122,300l. having been expended, the works stood still for want of money until 5th April 1786, when they were resumed; on the 31st of March 1778 the line was opened northward to Banbury; and on the 1st of January 1790 the whole was completed. Mr. James Barnes was employed to execute some of the digging of this part. This company have been

authorised to raise, by their different acts, 330,000l.; the amount of their shares is 100l. each. In January 1800 these are said to have sold for 194l., and in 1802 for 275l. each; the *Grand-Junction* company being bound to make up the tolls hereon to 10,000l. annually, (if the works are kept in order) on condition of this company taking only certain tolls on goods passing to or from that canal, (see *Phillips's 4to. Hist. Append.* p. 32.) and agreeing to widen about 35 miles of their canal and locks, that large boats may pass north of Braunston, whenever the *Grand-Junction* company shall require the same of this and the *Coventry* company. The rates of tonnage are rather complicated; they will be found in *Gary's Inland Navigation*, pages 59, 74, and 80. For parcels under 5 cwt. the company are to fix specific rates in their printed tonnage tables. Coals from the inland pits were not allowed, by the first act above, to come nearer to London than Oxford; but by the 3d act, this was extended to Reading and the *Kenet* navigation; and in the year 1800 this company offered 2s. per ton as a premium on coals carried certain distances from their canal into Berkshire, &c. The narrow barges used on this canal seldom venture down the *Thames* to London, but goods are generally shifted at Oxford into the *Thames*-barges. About the year 1792 the *Stratford and Croyder* canal was proposed to join this at Croyder; and, at the same time, a canal from *Hampton-Gay* to *Wsworth* was intended, to join this at Hampton-Gay.

PARNEL'S CANAL. This short canal, or rather water-level, has nearly a north direction for about $\frac{1}{2}$ a mile in the valley north of St. Austle, (near the south coast of Cornwall) one mile above that town; it commences within an immense excavation of great depth, and open to day, which has, by the work of ages, been made in a rocky hill abounding with tin ore. It is tunnelled through the solid rock for 200 yards or more, on a level to the surface of the hill, and proceeds forwards thereon to the top of an inclined plane, of about 50 feet fall, where the boats are raised up an end by a windlass to shoot out the ore, as already described on *St. Columb* canal. At the bottom of the plane the ore is loaded into carts, to be carted to the stamping-mills. Small square-headed boats are used, and four or five of them are linked together to be shoved through the tunnel, by means of chains which are fixed along its sides for that purpose, and they are afterwards towed along the canal to the head of the plane. This canal, tunnel, and plane, were made at the expense of Mr. Parnel, who owns the mine, about the year 1770, before which the ore was drawn up to the top edge of the pit or mine, and carted from thence.

PARRET RIVER. The course of this river is nearly south-east for about 5 miles, in the county of Somerset; it is not greatly elevated; its objects are the import of coals, and the export of agricultural products. Langport is the only considerable town near this navigation. It commences in the *Tone* and *Parret* navigation at Borough-Chapel, and terminates in the *Ivelchester* and *Langport* navigation, a little below Langport.

PEAK-Forest CANAL. Acts 34, 40, and 45 of Geo. III.—The general direction of this canal and rail-way is nearly south-east for 21 miles, in the counties of Chester and Derby; its southern end is very considerably elevated, and terminates on, or very near to, the Grand-Ridge; its principal object is the export of the Peak-Forest lime, and of coals from the neighbourhood of this canal. Ashton-under-line, Stockport, and Chapel-le-Grith are considerable towns on or near this line; which commences in the *Manchester Ashton and Oldham* canal, at Duckenfield, (near to the termination of the *Huddersfield* canal,) and the canal terminates

at the basin and lime-kilns in Chapel-Milton, whence a rail-way proceeds to Load-knowl lime-stone quarries in the Peak. The line of the canal is 15 miles in length, and of the rail-way 6 miles; there is a cut of $\frac{1}{2}$ a mile to Whaley-Bridge, and a rail-way branch of $1\frac{1}{2}$ mile to Marple. Over the Mersey river, near Marple, is a grand aqueduct bridge of 3 arches, each 60 feet span and 78 feet high, the whole height of the structure being near 100 feet, which was built in the year 1799. (This bridge we have before, by mistake, when treating of Aqueducts, mentioned as being on the *Manchester Ashton and Oldham* canal.) Mr. Benjamin Outram was the engineer, and the works were completed on the 1st of May 1800. The company were authorised to raise, by the first act, 150,000l., each share being 100l., which in 1802 bore a premium of 10 per cent. It has been said, on several occasions, that this canal and rail-way were completed at 10 per cent. under the original estimate, and that the 2d act authorised the company to raise any unlimited sum that they might want, in which there certainly were mistakes, because the act of the last session was for raising a further sum of money. For the rates of tonnage and wharfage, see *Phillips's 4to. History, App.* p. 155. Miue-waters may be used for the supply of this canal, but only the flood-waters of the rivers.

PENTLAND FIRTH. This strait has nearly a west direction between Caithness county, at the north-eastern extremity of Scotland, and the Orkney islands. This, though a rocky and dangerous passage, is much frequented by ships, on account of being the first passage which presents itself for ships in going northward, between the East and West Seas, or German Ocean and Irish Sea. The *Inverness* and *Fort-William* canal, now cutting a great way south of this for the use of ships, is expected much to lessen the use of this firth. Serabster roadstead, on the side of this firth, is a harbour much frequented by ships in blowing weather. Thurso harbour in Caithness, on the southern side of this firth, has a pier now building, and its harbour improving, under an act of 42 of Geo. III.

POLBROCK CANAL. Act 37 of Geo. III.—The general direction of this canal is nearly south-east for about 5 miles in Cornwall, near its north-west coast; it is not greatly elevated; its objects are the import of coals, and the export of stone and agricultural products. Bodmin is a considerable town near it. It commences at Guinea-port, near Wade-bridge, in the *Camel* river, and terminates at Dunmeer Bridge and Stoney Lane, in the parish of Bodmin, having a collateral cut of $\frac{1}{2}$ a mile to Ruther Bridge, in the same parish. At Guinea port and at Stoney-Lane Bridge large and convenient basins and warehouses are intended. Mr. John Rennie and Mr. Murray are the engineers. This company may raise 18,000l. in 50l. shares. A feeder from the *Camel* river and any springs within 2000 yards may also be taken for this canal.

POOLE HARBOUR. This spacious inlet or harbour has nearly a west course for about 9 miles, in the county of Dorset; the tide flows into every part of its various branches and inlets, and round Branksea island, which is in the middle of it; its object, besides the general trade and supply of the neighbourhood, is the export of a fine potter's clay found near to Corfe Castle, in the isle of Purbeck, and paving-stones and free-stone from thence. Poole, Wareham, and Corfe Castle are considerable towns near this harbour, which commences in Studland Bay and terminates at Wareham Bridge: a branch proceeds about 2 $\frac{1}{2}$ miles north to Creek-Moor. In 1797 several improvements in this harbour were in contemplation.

PORTSMOUTH HARBOUR. This inlet or harbour has

nearly a north course, for about $5\frac{1}{2}$ miles, in Hampshire; the tide flows through it, and the depth of water in most parts of it is sufficient for the large ships of the British navy. Portsmouth is the 13th British town, with a population of 32,166 persons; Gosport and Fareham are also considerable towns adjoining it. It commences at Spithead, in the Channel, between Hampshire and the Isle of Wight, and terminates at Fareham Bridge, having also a branch to Cosham, and a communication therefrom to Langstone and Chichester harbours. On the shores of this harbour there are immense buildings and works, for the use and security of the royal navy. In 1805 several considerable additions were making to these works, and a bridge between Gosport and Haslar hospital, which Mr. Robert Forbes built some years ago, is intended to be taken down, having proved injurious to the harbour.

Portsmouth and Croydon Canal. In the years 1802 and 1803, a canal was in contemplation from *Portsmouth Harbour* to the *Croydon Canal* at that town, passing Havant, Chichester, Arundel, Horsham, Ryegate, and Mertham, of which that able engineer, Mr. John Rennie, prepared plans and an estimate; but the opposition of the land-owners, and favourers of a rail-way scheme from *Portsmouth* to *London* procured its rejection in parliament. The summit-level of this canal was to be 36 miles in length, at about 220 feet above the level of the sea: this was to be fed by several reservoirs in or near Horsham Forest, containing in the whole 500 acres, and 340,000,000 cubic feet of water. This level was to penetrate the Chalk-Hills north east of Mertham, by a tunnel $4\frac{1}{2}$ miles long, and 350 feet below the top of those hills. The estimated expence was 721,000*l.*, and 800,000*l.* in 1801. shares was proposed to be raised; the expected revenue was estimated at 100,000*l.* per annum. While this line was in contemplation, there was an attempt made by Mr. Ralph Dodd to draw the public attention to a different line of canal, (which Mr. John Phillips laid claim to, as being one of the fanciful ones which he has drawn in the map to his 4to. History, 1791.) from *Portsmouth Harbour*, through *Southampton Water* and the *Tichen River*, to Winchester; thence to Alresford, near to Alton and Farnham, and to the Wey river at Godalming: from near Westley on that river, the proposed line of the *Grand Surrey* canal was to be followed to Deptford and the *Thames* river. The estimate mentioned on this occasion was 348,735*l.*

Portsmouth and London Rail-way. In 1803, Mr. William Jessop was employed to survey the line of a rail-way from *Portsmouth* town to the west end of Stamford-Street, near Blackfriars-Bridge, London; on the utility of which, and the *Portsmouth and Croydon* canal above, opinions were for some time divided: in the end, neither of them was adopted. The estimated expence of this work was 400,000*l.*

RANSDEN'S CANAL. Act 14 Geo. III.—The general direction of this canal is nearly south-west for about 8 miles, in the West Riding of Yorkshire; it is not very greatly elevated; its objects at first were the supply and trade of Huddersfield town, but it will shortly have considerable importance as part of the shortest line of navigation between Hull and Manchester and Liverpool. Huddersfield is the 81st British town, with a population of 7268 persons. This canal commences in the *Calder and Hebble* navigation, at Cooper's Bridge, and terminates in the *Huddersfield* canal, at King's Mill near Huddersfield; it has a rise of $56\frac{3}{4}$ feet by 9 locks. Sir John Ramsden, who is the sole proprietor of this canal and of Huddersfield town, in 1766 employed Mr. James Brindley to plan this canal; and, after his death, it was begun and quickly completed by Mr. Luke Holt. At Huddersfield spacious warehouses are built by the side of this

canal, to which goods intended to be there lodged may be carried toll-free along the part of this canal from the *Huddersfield* canal; that company guaranteeing the tolls on this not to be lessened thereby. On the whole length or any part of this canal, coals, flags, slates, stones, lime stones, and lime, are to pay a toll of 3*d.* per ton, and all other goods 1*s.* 6*d.* per ton, except dung and manures, which are to pass free. The proprietors' profits are never to exceed 6 per cent. upon the monies laid out thereon.

Reading and Maidenhead. In 1770, a canal was proposed from the *Thames* river, at Bolter's Lock near Taplow-Hill, (at the western termination of the *Maidenhead and Isleworth* proposed canal,) to the *Thames* again, at Sunning near Reading and to the *Kenet* river, on which Mr. James Brindley was consulted by the city of London, the distance being near 15 miles by the canal, and by the river above 30 miles, between the same places; a barge of 120 tons being 3 days (and often in dry times as many weeks) in performing the voyage, at an expence equal to 50*l.*; while, by this canal, it was calculated that a barge might at all times, except frost, perform it in 6 hours, at 4*l.* 7*s.* expence, including $\frac{1}{2}$ *d.* per ton to the trustees as a toll. This canal was at first proposed to commence at Monkey island in the *Thames*, which is 2 miles below Maidenhead-Bridge. No private property was to be allowed in this canal, but the money was proposed to be raised by life annuities, out of which, and the tolls, the river navigation was to be improved between Bolter's Lock and Sunning, without any new tolls being charged thereon; and when a sufficient fund was accumulated for repairs and management, the tolls were to cease, and the canal be entirely free.

RIBBLE RIVER. The direction of this river is nearly east for about 12 miles in the county of Lancaster; the tide flows through its whole length: its objects are the supply and trade of Preston town, and the export of coals brought down by the *Douglas* river, which joins it near Hasketh. Preston is the 37th British town, with a population of 11,887 persons. This river commences with a very wide estuary or mouth in the Irish Sea, but grows very shallow, so as to be fordable at low-water, and terminates at the bridge at Preston, near to the aqueduct bridge, on which the *Lancaster* canal crosses this river. In September last, (1805) it was proposed to apply for an act for placing buoys, and otherwise improving the navigation of this river.

RIPON CANAL. Act 7 Geo. III.—The general direction of this canal is nearly N.W. by a bending course of about 7 miles in the West, and skirting the North Riding of Yorkshire: its objects are the supply of Ripon, and the export of agricultural products, stone, &c. It is considerably elevated; Borough-bridge, Ripon, and Aldborough, are considerable towns on or near this canal, which commences in the *Tore* river at Milby, near Borough-bridge, and terminates at Ripon.

ROCHDALE CANAL. Acts 34, 40, and 44 of Geo. III.—The general direction of this canal is nearly N.E. by a bending course of $31\frac{1}{2}$ miles in the counties of Lancaster and York; it crosses the grand-ridge by a deep-cutting: its general objects are the communication between Liverpool and Manchester, with Halifax, Wakefield, Hull, &c. the export of coals, paving-stones, &c. At Piccadilly street in Manchester it is joined by the *Manchester Ashton and Oldham* canal. Manchester is the 2d British town, with a population of 84,020 persons; Huddersfield is the 44th, with 10,671 persons; Spotland the 55th, with 9,031 persons; and Halifax the 58th, with 8,886 persons. This canal commences in *Bridgewater's* canal at Castle-Field in Manches-

ter, and terminates in the *Calder and Hebble* navigation at the basin, wharf and warehouses at Sowerby bridge: to near Hollingwood chapel there is a branch of $\frac{1}{4}$ of a mile, and another of $\frac{1}{4}$ a mile to School-lane in Castleton near Rochdale. From *Bridgewater's* canal to Piccadilly wharf, and the *Manchester Ashton and Oldham* canal, $1\frac{1}{2}$ mile, has a rise of $75\frac{1}{2}$ feet; thence to the Hollingwood branch, $4\frac{1}{2}$ miles, has a rise of 81 feet; thence to Failsworth brook, $2\frac{1}{2}$ miles, is level; thence to the Rochdale branch, $4\frac{1}{2}$ miles, has a rise of 120 feet; thence to Clay-hall, $2\frac{1}{2}$ miles, has a rise of 62 feet; thence along the summit-pound and through the deep-cutting to Travis-mill, $5\frac{1}{2}$, is level; thence to the *Calder and Hebble* navigation, $11\frac{1}{2}$ miles, has a fall of 275 feet; the Hollingwood and Rochdale branches are level. From near Rochdale to Sowerby-Bridge there are 49 locks, (which are of the same width and length as *Bridgewater's* at Run-corn:) more than 60 bridges and 8 aqueducts and large culverts. At Halli's mill is a tunnel of 70 yards in length, 17 feet high and 21 feet wide, with a towing-path through it. At Dean-Head, between Littleborough and Todmorden, is a stupendous deep-cutting in hard rock, some of it 50 feet deep. A very large reservoir is made on the west side of the summit, and an 100 horse steam-engine is used to pump the water up to the summit-pound. On a bog on Blackstone edge are two other large reservoirs, one of them 14 yards deep. Gauges for regulating the streams of the Roch, Irwell and Irk rivers, so that only their surplus flood-waters are taken for the supply of this canal, were contrived and erected by Mr. *John Rennie*, the engineer. Steam-engines within 20 yards of the canal are allowed to condense by its water. On the 28th of December 1798, the east end of the line from Sowerby bridge to Rochdale was completed; on 18th September 1802, it was continued to Lome-side wharf; and on 21st December 1804, the whole line was completed and opened to Manchester. This company are to pay a compensation to the duke of *Bridgewater* for his warehouses at Castle-Field, and to the *Calder and Hebble* company for their warehouses at Sowerby bridge. This company were authorised by their first act to raise 391,000l. (the amount of shares 100l. each) and by the last act they were authorised to raise a large sum in addition. The rates of tonnage and wharfage, and the exemptions in the first act, will be found in *Phillips's 4to. History*, pages 157 and 159, to 161; also, by the second act, certain additions were made to these tolls. Cuts or rails-ways may be made to any present or future coal-mines near the line. In 1791 a branch from this canal was proposed from near Todmorden (104 feet below the summit-level) to 2 miles beyond Colne, having a tunnel thereon of $1\frac{1}{4}$ mile in length, about 3 miles N. E. of Todmorden.

ROTHER RIVER. The general direction of this river is nearly N.W. by a crooked course of about 19 miles in the counties of Sussex and Kent; it is but little elevated above the sea in any part: its objects are the import of coals, &c. and the export of oak-timber and agricultural products: near Rye harbour, opposite to Pleydon-heights, it is joined by the *Shorncliffe and Rye* canal. Rye, Winchelsea, Appledore, and Tenterden are considerable towns on or near to this navigation; which commences in the tide-way of the English Channel near Rye old harbour, and terminates at Roberts-bridge; it has a branch of about $2\frac{1}{2}$ miles to Winchelsea bridge, and some other navigable branches in the level fens which surround Oxney Island, and adjoin Romney-marsh. The harbour of Rye near the mouth of this river, from its tendency to choke up, formerly employed the abilities of captain *John Perry*, Mr. *John Smeaton*, and other eminent engineers; and under the acts of 29 Geo. I. and I, 37, and 41 of Geo. III. several works have

been constructed. Previous to the reign of Edward I., it is said, that the *Rother* vented its waters into the sea at old Romney harbour, about which time a new channel was cut for it to sea at old Rye-harbour, which for a long time scoured itself out, and was deep enough for the use of large vessels, the tide flowing 24 miles up the river; but sea-fluices being afterwards erected in improper situations, and embankments made, by which (before 1698) the channel became too shallow for ships, and in 1719 it was rendered quite useless for navigation; soon after 1721, the sluices above mentioned were removed, but the evil was become so irreparable, that captain *Perry* advised, and effected the cutting of, an entire new channel of about a mile in length, 150 feet wide at top, and 70 at bottom, since called the new harbour (from the sea, near 2 miles west of the old harbour) into the channel of the Winchelsea river, and through that to the *Rother* and old harbour at Rye; this new canal (finished 14th July 1762) had about its middle part, a stone sluice of two openings, one for the passage of vessels, and the tide near high-water, 40 feet wide, shut by double gates pointing to Landward, and another of 30 feet wide, closed by 5 draw-gates, to be occasionally opened for scouring the mouth of the new channel or harbour, at which there were two stone piers erected at 120 feet apart. The upland and tide waters continued to have their course to sea by the old channel or harbour, and Mr. *Smeaton* who was consulted in 1763, confidently foretold, that unless the old channel was closed up near Rye, below the entrance to the new one, so as to turn the upland waters through the new harbour, it would be in time quite filled up, as happened so completely previous to 1797, that an act then passed repealing all the former acts relating to this new harbour, and the tonnage which coasting vessels had paid since it was established, on passing or entering the same, was transferred to Ramsgate harbour, near *Stour* river, into which such ships are able to run for shelter, in case of a storm coming on. The new Rye-harbour was in consequence blocked up, by a bank below the Winchelsea river, over which the new road between Winchelsea and Rye now passes: soon after this, the *Rev. Daniel Pappe* revived the ideas of Messrs. *Perry* and *Smeaton*, with regard to the entrance of the old harbour, and by the assistance of Mr. *Sutherland*, cut a new channel, or sea vent, for the river, about $\frac{1}{4}$ of a mile west of the old harbour's mouth, and being about $\frac{1}{4}$ of a mile in length, before it intersected the old harbour: at this place Mr. *Pappe* constructed a dam of straw, faggots, and gravel, which effectually blocked up the old harbour's entrance, and forced the tide to enter and return, and the river waters to vent themselves through his new cut (as Mr. *Smeaton* had in vain before recommended to be done with Mr. *Perry's* new cut.) After which, Mr. *Sutherland* constructed a pier-head on the east side, and two jetties on the west side of the present entrance to the harbour, which is now said (see *Transactions of the Society of Arts*, vol. xxii. p. 249) to be capable of admitting ships of 250 and 300 tons burthen at spring tides, which here rise 23 feet, and the neap tides 14 feet. In December 1799, it was proposed to improve the navigation of this river between Rye and Roberts-bridge, to extend the navigation of the Winchelsea branch to Siddlecombe, and to make a new navigable branch from Blackwall to Smallhithe near Tenterden. In April 1802, this last branch was proposed to be joined by the intended *Medway and Rother* canal.

Sandbach Canal. In the year 1793, a canal was proposed to be made from the *Severn* river below Shrewsbury to the *Trent and Mersey* canal at Sandbach, with a cut to Betley, and another to join the *Chester* canal near Nantwich. The *Ternbridge and Winsford*, and the *Newport and Stone* canals,

have at different times been proposed through parts of the same tract of country.

SANKEY CANAL. Acts 28 of Geo. II. and 1 of Geo. III. —The general direction of this canal is nearly N.W. by so very bending a course, that it exceeds a semicircle; its length is 12½ miles in the county of Lancaster; it is not very greatly elevated in any part: its objects are the export of coals and slates, and the supply and trade of St. Hellens and Newton, and the copper, glass, and other works near them; near Sankey bridge it connects with, and is crossed by the side-cut made in 1804 for avoiding the shallows in the *Mersey* between Warrington and Runcorn. Warrington is the 45th British town, with a population of 10,567 persons; Newton and St. Hellens are also considerable towns near, or on this canal; which commences in the *Mersey* and *Irwell* navigation at Fiddlers-ferry, and terminates near Sutton-heath collieries. Near the mouth of Sankey brook it has a short cut of about ¼ of a mile, forming another communication with the *Mersey* river; there is a branch of about ½ of a mile to Penny bridge, and another of ¼ of a mile to Gerrard's bridge. From the *Mersey* to Sutton heath is a rise of 78 feet, by 8 six-foot locks, and 2 double locks of 15 feet rise each. The highest spring tides rise within about a foot of the level of the water at the first lock. Vessels deeply laden were generally unable to pass into or out of the *Mersey* for two or three days of neap tides before the *Mersey* cut above mentioned was made. This canal is 48 feet wide and 5½ feet deep in water; it has 18 bridges, all of which are wooden swing-bridges, even for the great turnpike road between Manchester and Liverpool. Between St. Hellens and Sutton-heath there is a short tunnel; the canal is fed by a feeder from Sankey brook, and there are provisions for enabling the farmers near this canal to irrigate therefrom, between the 10th of October and 1st of May annually. Mr. John Eyes was the engineer, and has the honour of completing this, the first English canal, that was attempted; it was opened between the *Mersey* and Gerrard's bridge in the year 1760. The sum of money to be raised for the purposes of this canal is not limited in the acts, as is done in all modern canal acts. The proprietors are authorised to take 12d. per ton on all goods which are navigated on any part of their canal, except limestone, road-materials and manures, which are toll free: 63 cubical feet of coal, cannel, charcoal, coke, or cinders, are to be rated as a ton, and a bushel of coals is to be heaped measure in a vessel 19½ inches diameter outside, and capable of containing one bushel and one quart of water Winchester measure. In June 1797, a loaded barge was rowed 20 miles on this canal by a machine worked by a steam-engine on board of the barge, as before mentioned.

Selby and Leeds. In 1769, Mr. James Brindley surveyed the line of a canal from the *Ouse* river at Selby to the *Leeds and Liverpool* canal (near to the termination of the *Ayre and Calder* navigation) at Leeds: it was proposed to pass Thorp dam, near to Thorp hall, Hambleton, Hillham, Burton-Salmon, (where a tunnel was intended,) near Fairburn, Newton, the Fire engines, and cross the *Ayre* river, by Thwait mill, Hunstet, and so on to Leeds, a course of 23 miles in length: the opposition of the *Ayre and Calder* company, who were in the reign of William III. indulged with very high rates of tonnage, and some other persons, proved fatal to this scheme when it came before parliament.

SEVERN RIVER. Acts 19 Hen. VII., 23 Hen. VIII. and 12 and 43 of Geo. III. —The general direction of this noble river is nearly north, by a crooked and bending course of about 174 miles, skirting the counties of Somerset, Gloucester, Glamorgan, Monmouth, and Hereford, and

through the counties of Worcester, Salop, and Montgomery; commencing in the tide-way in the *Bristol Channel*, at Flat-Holm light-house, and terminating in the *Montgomery* canal at Welshpool. Its northern end is considerably elevated: the trade of various kinds is very immense on this important river, and the many navigations which connect therewith. At the lower layer it is joined by the *Glamorganshire* canal and *Cardiff and Merthyr-Tydvil* rail-way; at New Amsterdam by the *Sirhowy* rail way; at Nash by the *Ufke* river; (not far from its junction with *Monmouthshire* canal, and a branch of *Sirhowy* rail-way); at King's Road by the Bath *Avon* river; at Beachley by the *Wye* river; at Berkley-Pill, Hotch-Crib, and at Gloucester by the *Gloucester and Berkley* canal; at Framiload by the *Stroudwater* river and canal; at Gloucester, on each side of Alney Isle, and at Laffington by the *Hereford and Gloucester*; at Fletcher's leap with *Coombe-hill* canal; at Tewksbury by the *Stratford Avon*; at Diglis by the *Worcester and Birmingham*; at Hawford by the *Droitwich* canal: at Stourport by the *Stour* river and *Staffordshire and Worcester* shire, and the *Leominster* canals; at Coal-port and at Loads-croft near Coalbrookdale, by the *Shropshire* canal; and at Shrewsbury by the *Shrewsbury and Ellesmere* canals. Bristol is the 7th British town, with a population of 68,645 persons; Shrewsbury the 36th, with 14,739 persons; Worcester the 40th, with 11,352 persons; and Gloucester the 72d, with 7,579 persons; Cardiff, Newport, Chepstow, Thornbury, Berkley, Newnham, Tewksbury, Upton, Bewdley, Kidderminster, Bridge-North, Much-Wenlock and Welshpool, are also considerable towns near to, or upon this river. The falls which this river has in particular parts have been mentioned in a preceding part of this article, as also a valuable experiment of 11 years continuance on the floods, droughts, and frosts which affected its navigation; which is unassisted by any locks, side-cuts, weirs, or other erections, except the towing-paths, which Mr. William Reynolds begun between Coal port and Coalbrookdale, in consequence of an act, 12 of Geo. III., since renewed, for making a towing-path between Coalbrookdale and Bewdley bridge, and levying certain tolls on goods navigated on that part of the river for defraying the expences of such path, which has been since completed; and in 43 of Geo. III. a similar act for making a towing-path from Bewdley bridge to the *Worcester and Birmingham* canal at Diglis below Worcester, which is, we believe, also completed. The trade on the middle parts of this river is carried on by two sorts of vessels, viz. barges 40 to 60 feet long with a single mast and square sail, carrying from 20 to 40 tons, and trows with a main and top-mast about 80 feet high, and square sails; these are 160 feet long and 16 to 20 feet in width, and carry 40 to 80 tons. Some years ago, Mr. John Wilkinson introduced some barges made of cast iron plates for navigating this river. In the 16 Geo. III. an act was obtained for erecting a cast-iron bridge of one arch (the first ever erected; see our article BRIDGES) over this river at Brosely or Madeley wood near Coalbrookdale. The high floods, in 1795, carried away a narrow and inconvenient stone bridge that was at Buildwas, about 2 miles above Madeley wood, and in 1796, a new cast-iron bridge was erected in its stead, as before described: by an act of the 17 Geo. III. a new stone bridge was erected over this river at Gloucester, by which the navigation there was much improved. At Shrewsbury the very long and curving loop of the river is tunnelled through by a small arch for conveying water to several mills at its junction again with the river. In the year 1765, the *Ternbridge and Windsor* canal was proposed to join this river at Ternbridge; in 1786 the *Stourbridge and Worcester* was proposed to join at Diglis; in 1793, the *Sandbach*, and

another canal in opposition to the *Ellesmere* (called, in some maps, the Eastern Grand Trunk,) were proposed to join this river below Shrewsbury. In 1795, the *Wellspring and Locominster* was intended to join at Wellspring; in 1797, the *Bristol and Gloucester* was proposed to join, both at Gloucester and at Worcester, to this river; and, in 1801, the *Severn and Wye* rail-way was proposed to join this river at Lidney.

Severn and Wye Rail-way. In the year 1801, a line of rail-way was projected from the *Severn* river at Lidney, across the forest of Dean, connecting with the collieries thereon, and extending to the *Wye* river at English Bicknor, we believe. At a meeting, on the 14th of June, 1802, the southern part of this design was relinquished, and the *Dean-Forest* rail-way was proposed in lieu of the other part.

SHANNON RIVER, (Ireland). The general direction of this famous river is nearly N.E. by a crooked course of more than 100 miles, between the counties of Kerry, Limerick, Clare, Tipperary, Galway, King's county, Meath, Longford, Elphin, and Leitrim in Ireland. It commences in the Atlantic Ocean, at Loop-head, and terminates at Carrick on the Shannon, which is 65 miles above Banagher. It is joined by the *Grand Canal* at Tormanbury, and it also is joined by the *Limerick canal*. Limerick, Kilaloe, Clonfort, Leitrim, Carr, Longford, Roscommon, Athlone, Portumny, Nenagh, Askeaton, Clare-Abbey, &c. are considerable towns on or near to this river. About the year 1750, the improvement of the navigation on this river was attempted, by the erection of sluices with gates on its stream, for damming up and making flashes for the boats to pass through with. The Irish parliament, at different periods, between 1753 and 1771, granted several sums of the public money, amounting to 39,160*l.* for the improvement of this navigation. It was not until about March 1804, that the upper part of the navigation on this river was completed.

SHORNCLEIFF AND RYE CANAL. Defence act 43 Geo. III.—The general direction of this singular canal is nearly S.W. by a bending course of about 18 miles, through Romney marsh in the counties of Kent and Sussex. It is so nearly level with the sea as to require no locks but the tide-locks at its extremities. Its objects, besides aiding the defence of this part of our coast, is the import of coals and sea-beach for road-making; the export of farming products, and improving the drainage of the marsh: Hythe, Rye, Appledore, and Folkestone are considerable towns near this line; which commences in the tide-way of the English channel at Slorncliff battery near Hythe, and terminates in the tide-way of the *Rothe* river opposite Pleydon Heights near Rye. This canal is of width and depth sufficient for vessels of 200 tons to navigate; it has a military road by its side, and is flanked throughout with batteries of great strength. This canal was projected by the royal military engineers, in the autumn of 1804; and in June last (1805) 3000 men were said to be employed thereon, and before now it is, we believe, completed.

SHREWSBURY CANAL. Act 33 Geo. III.—The general direction of this canal is nearly E. by a crooked course of 17½ miles in length, in the county of Salop: its eastern end is greatly elevated, and at no great distance from the grand-ridge on its western side; its objects are the export of coals from its eastern end, for the supply of Shrewsbury, and supplying the same with farming products, and the country with lime and manures; at Wombridge it is joined by the *Ketley* canal. Shrewsbury is the 36th British town, with 14,739 persons. This canal commences in Castle Foregate basin, at the town of Shrewsbury, (near to the *Ellesmere* canal, with which it may be joined by mutual consent,) and terminates in the *Shropshire* canal above Wrockandire-wood plane near Oaken-gates. From Shrewsbury to Langdon,

near 12 miles, is level; thence to near Wombridge, 4½ miles, is a rise of 79 feet, by locks; thence is an inclined plane of 75 feet rise, and near ¼ of a mile in length, to the *Ketley* canal; thence (along the part which was purchased by this company of Mr. William Reynolds for 840*l.* being half of what it cost) to the *Shropshire* canal, 1½ mile, is level. The locks on this canal are contrived in two divisions by doors, which draw up, out of a recess formed for them below the locks, so that a long narrow canal boat of the usual construction, or two or four smaller and narrow flat-bottomed boats adapted to the inclined-plane, can pass the same without unnecessary waste of water. Near Atcham is a tunnel of 970 yards in length, and 10 feet wide, which has a towing-path 3 feet wide through it, constructed of wood, and supported on bearers from the wall, so as not to diminish the water-way. At Long is a long embankment and an aqueduct bridge, or rather trough of cast iron, over the Tern river, 62 yards long, and 16 feet above the level meadows, of which we have already given a description in this article; at Roddington are another embankment and a common aqueduct bridge, 21 feet above the surface of the Roden river, over which the canal passes, and at Pimley there are another embankment and aqueduct of less height and width than the former ones. At Wombridge there is a double inclined-plane of 223 yards in length, and 75 feet perpendicular rise, up one of which, empty or partly laden boats are drawn by the aid of a steam-engine, or by the descent of a loaded boat at the same time on the other, as we have before described. Mr. Thomas Telford and Mr. William Reynolds were the engineers employed or consulted on the construction of the works on this canal. In March 1796, the Long aqueduct was finished; and in February 1797, the whole line was completed and opened. This company was authorized to raise 70,000*l.* the amount of each share being 100*l.* The rate of tonnage is 2*d.* per ton per mile on all goods, and 1*d.* per ton for passing the inclined-plane; manures, except lime, being exempt on the pounds, but not to pass the locks when the water is ½ an inch under the lock-weirs. The profits of this concern are not to exceed 8 per cent. on the capital, after which the toll on boats for passing the plane is to be first lowered or taken off. The act in providing for the purchase of 1½ mile of Mr. Reynolds's *Ketley* canal as above, requires him to pay 2*d.* per ton per mile afterwards for navigating the same, as above. Less than 8 tons in a boat, except in returning, is to be paid for as such.

SHROPSHIRE CANAL. Act 28 Geo. III.—The general direction of this canal, or rather system of water-levels and inclined-planes, is nearly north, about 7¾ miles, in the county of Salop: its northern end is greatly elevated, and at no great distance from the grand-ridge on its western side; its objects are the export of coals and iron, and the carrying up of lime-stone. It communicates near Oaken-Gates with the *Shrewsbury* canal; it has no large town near it. It commences in the *Severn* river at Coal-Port, (a new town established by the late excellent Mr. William Reynolds, whose rapidly increasing manufactories in the year 1800 employed 400 persons,) and terminates in the *Donnington-Wood* canal at Donnington-Wood. It has a branch from Southall Bank, which proceeds to Brierly Hill near Coalbrook-dale (2¾ miles), and thence is continued by an inclined plane and rail-way below, to the *Severn* at Loads-Croft, near the Brosley iron bridge. There is also a short rail-way branch to Horse-Hay iron works. At the *Severn* river at Coal Port (formerly called Sheep-wash Meadow) there is a flood-lock, which rises sufficient to clear the highest floods in the river, parallel to which the canal proceeds on a level, ¾ of a mile, to near Hay, where is an inclined plane of 350 yards long and 207

feet perpendicular rise; thence to near Windmill Farm, $1\frac{1}{4}$ mile, is level canal, where is another inclined plane of 600 yards in length, and 126 feet perpendicular rise; thence to the Brierly branch at Southall-Bank, $2\frac{3}{4}$ miles, is level canal; thence to the *Strewbury* canal at Oaken-Gates, 3 miles, is level; thence to near Wrockardine-Wood, $1\frac{1}{4}$ mile, is also level: at this place is a third inclined plane, of 320 yards in length and 120 feet perpendicular fall; thence to the *Donnington Wood* canal, 100 yards, is level. The boats are shallow, and carry 5 tons. There are no locks on this canal, which is supplied with water by two small reservoirs which lie above the canal, and two others below its level, the water therefrom being pumped up by the steam engines belonging to the inclined planes; the waters which are lifted from the mines contribute also materially to the supply of the different lengths of canal. The three great inclined planes at Hay, Windmill, and Wrockardine, have each a short inclined plane descending from their tops into the upper canals, up which the boats, on a proper wheeled carriage, are dragged by the steam-engines, working the wheels, drums, and ropes, and are, by the ascent of another boat, or the operation of a brake-wheel, let easily down the long plane, as has been particularly described already in this article. At Brierly-Hill the crates or iron baskets of lime-stone were drawn up, and the coals in boxes were let down, through perpendicular shafts, 120 feet deep, by ropes winding on a drum above; but several years ago this plan was laid aside, and an inclined plane, similar to the three others above, except that it has no steam-engine, has been adopted, as before mentioned. Six boats have been passed down, and as many taken up, the Windmill plane of 600 yards long, in the course of a single hour; the steam-engine and 3 men only being employed. It is said that only 3d. is charged for letting down a loaded boat, and empty ones are returned gratis. Mr. William Reynolds and Mr. Henry Williams were the engineers; and the works were completed, and the canal opened in the year 1792; it is said to have cost only 47,500l. The rate of tonnage is 2d. per ton per mile on all kinds of goods. In the year 1797, the tolls produced a net profit of 6 per cent. on the capital.

SIRHOWY RAIL-WAY. Act 42 Geo. III. (for *Monmouthshire* canal).—The general direction of this rail-way or tram-road is nearly N. W., for about 28 miles, in the counties of Monmouth, and of Brecknock in South Wales: its northern end is much elevated: its object is the export of coals and iron from the rich mineral country through which it passes: at Court-y-billa farm, and at Risca, it is joined by rail-way branches of the *Monmouthshire* canal. Newport is a considerable town near its southern extremity: it commences at the *Uffe* river, near Pill-Gwenly (opposite the commencement of the *Monmouthshire* canal), and terminates at Trevil lime-stone quarries, in the parish of Llangunider; and it has a branch to Rumney union iron works; the line passing through Sirhowy and Tredegar iron works, and through Tredegar park; it was said also, that a branch of the rail-way was to be conducted from near Tredegar park to the meadows near the *Severn* river, where a new sea-port town, to be called New Amsterdam, was laid out and begun. This company were authorised to raise 45,000l., the amount of their shares being 100l., and they have engaged to pay 110l. annually to the *Monmouthshire* canal company, on condition of their constructing the first 9 miles of this tram-road nearest to *Uffe*; Sir Charles Morgan is to make 1 mile in length of the same through his park at Tredegar, and receive the tolls thereon; and Messrs. Samuel Homfray, Richard Fothergill, Matthew Monkhouse, William Thompson,

William Forman, and other iron-masters, are also to construct particular parts of this concern. It was provided, that if these several parties failed to execute their several parts of the line, previous to Michaelmas day 1803, that the act, as far as relates hereto, should be void. A new turn-pike road is made by the side of this rail-way for 21 miles: the ascent of the rail-way is so easy and regular that one horse can draw 10 tons down the line, and return with the empty trams. A new town was laid out and begun at Tredegar new iron works, near Sirhowy.

SLEAFORD NAVIGATION. Act 32 Geo. III.—The general direction of this navigation is nearly west, for about 12 miles, in the county of Lincoln: it is but little elevated above the sea, the greater part of it being embanked on both sides through level fens: its objects are the supply of Sleaford and the surrounding country with coals, deals, &c., and the export of farming produce. Tatterhall and Sleaford are considerable towns near this navigation. It commences in the old *Witham* river at Chapel-Hill (not far from the commencement of *Horncastle* canal), and terminates at the cattle-caufeway near Sleaford. The locks are 60 feet long, and 15 feet wide in the clear; the width of the canal is 30 feet at top, 18 at bottom, and four feet deep, except the summit pound from Haverholm mill to Sleaford, which is to be 5 feet deep, to make a reserve of water, which is to be supplied from the fens above the navigation in New Sleaford. This company was authorised to raise 23,000l., the amount of shares 100l. each. The tolls are various for different parts of the line. See *Phillips's* 4to. *Histroy, Appendix*, p. 26. Lime, manures, and road-materials pay only half the rates of other articles. The profits of this concern are limited to 8 per cent. and after 1000l. is accumulated as a fund for contingencies, the tolls are to be lowered. This company are to join with the *Horncastle* canal company, in the expence of improving the old *Witham* river between Lincoln high bridge and the *Foss-dyke* navigation at Brayford-Meer; in consequence of which only half the usual tolls on the old *Witham* are to be taken, on goods passing to or from these navigations.

SOHAM LODGE. The direction of this navigable cut or lode is nearly S. E., for about 4 miles, and is embanked through the level fens in Cambridgeshire: it commences in the great *Ouse* river, near Barway chapel, and after passing through Soham-Meer, terminates at the town of Soham: its objects are the supply of coals, &c. to Soham, and the export of farming products.

SOMERSETSHIRE COAL CANAL. Acts 34, 36, and 42 Geo. III.—The general direction of this canal is nearly S. W., for about 10 miles, besides a principal branch of $7\frac{1}{2}$ miles nearly parallel thereto, in the county of Somerset: its western ends are considerably elevated: its object is the export of coals from the mines north of Mendip hills. Bath is the 12th British town, with a population of 32,200 persons, and Bradford the 78th., with 7,302 persons, which are the only large towns near this canal; which commences in the *Kennet and Avon* canal, at Monkton Coombe, and the main or Dunkerton line of canal terminates at Paulton; but a rail-way continues it forwards to Tynning; the Radstock line or branch of canal proceeds from the last at Mitford mill, and terminates at Radstock town; but a rail-way continues it forwards to Welton colliery; there are also rail-way branches from this line to Radstock colliery, and to Smallcombe and Clandon collieries: from the main or Dunkerton line, there are rail-way branches to Mearns, Amesbury's, Britton's, Salisbury's, and Radford collieries. From the *Kennet and Avon* canal to Mitford mill is level, thence the main or Dunkerton line

rises 138 feet by 22 locks. The Radstock line rises about the same height from Mitford mill. The boats used are 72 feet long, and 7 feet wide. About July 1796, Mr. Robert Weldon began the erection of one of his diving or caisson locks at Coombe-Hay, for passing the boats through a perpendicular shaft, either in ascending or descending. In November 1797, this apparatus was in sufficient forwardness for the caisson to be sunk and raised again in the shaft; and, in May 1798, a trial was made of this contrivance, so successful, that the inventor then offered to undertake to pass 1500 tons of goods in 12 hours through this 45 feet rise or fall, without the loss of any considerable quantity of water, and with the assistance of only one man, besides the bargemen, to work the machinery. These fair prospects were, however, blighted, by the bulging of the walls of the shaft, as we have already mentioned, in describing this contrivance; and inclined planes were constructed at this place for letting down boxes full of coals, the descent of which, by means of ropes and wheels, drew up the boxes, either empty, or in part loaded with other goods: the delay and expence of this method being highly complained of, about September 1802, a new subscription was set on foot, and encouraged by the *Kennet and Avon* and *Wilts and Berks* companies, for substituting locks, 22 of which were completed, and opened on the 5th of April last (1805). Mr. John Rennie, Mr. William Bennet, Mr. Charles Wedge, and Mr. William Smith were the engineers consulted or employed upon this canal, which, in January 1801, was completed from Dunkerton to several of the coal mines, and which, (after 4 miles of land carriage,) had the effect of lowering coals at Bath from 14d. or 15d. per cwt. to 9d. or 10d. This company was authorised to raise 185,000l., the amount of shares 100l. each. Before undertaking any of the rail-way branches to the collieries, this company might require security from the owners of such collieries, that the tolls thereon should produce, or be made up, to a certain rate of interest on the cost of such branches. The profits of this concern are not to exceed 10 per cent.; but after 1000l. is accumulated and placed in government securities, as a fund for contingencies, the tolls on coals are to be lowered. Husbandry and pleasure boats 12 feet long and 5 feet wide may be used toll free on the pounds, or where the water flows waste over the lock-weirs. A tunnel, $\frac{3}{4}$ of a mile long, was at first proposed near Coombe-Hay, but by a subsequent alteration of the line this was avoided. The rates of tonnage in the first act may be seen in *Phillips's 4to. History*, App. p. 16; and 164, including the tolls on horses, cattle, sheep, &c. travelling on the rail ways; by the last act some of the tolls were increased. Dunkerton mill was purchased by this company, and steam-engines were erected to pump up water for supplying the upper pounds. In several places this canal was cut through *strata* disposed to slip, but by the small tunnels or soughs which Mr. William Smith constructed, for draining off the springs, the same was prevented. On the 3d of May, 1804, a sudden and great flood happened, which required, it was said, some of the banks of this canal to be cut in proper places, to give vent to the water.

SOUTHAMPTON AND SALISBURY CANAL. Acts 35 and 40 of Geo. III.—The general direction of this canal is nearly N.W. for about 17 miles, in two detached lengths, in the counties of Hants and Wilts; it is not greatly elevated; its objects are the trade between Southampton and Salisbury, the supply of these towns, and the export of the surplus farming produce of the intermediate country. This canal commences in the *Itchin* river, at Northam near Southampton, and proceeds along the N.E. shore of *Southampton water*

to the *Andover* canal at Red-bridge. In the *Andover* canal (about $\frac{9}{10}$ miles above Red-bridge), near Kimbridge mill, this canal commences again, and proceeds to the *Avon* river at Salisbury, or New Sarum. Southampton is the 68th British town, with a population of 7,913 persons, and Salisbury is the 70th, with 7,768 persons: Romley is also a considerable town near this line. The eastern part of this canal, between Northam and Red-bridge is level, and but little elevated by its tide-locks, above the tide-way in *Itchin* river and *Southampton Water*; from its skirting along close to the shore of the latter river, it was that that facetious satirist *Peter Pindar* took occasion to burlesque "Southampton's wife sons." Upon this part of the canal there is a tunnel of considerable length close to, and indeed under part of the north end of Salisbury town; considerable difficulties seem to have attended the making of this tunnel, owing to the looseness of the soil; and the quick-sands at the foot of the cliff, by the side of *Southampton Water*, have also proved a very serious obstacle. An aqueduct is built over Shirley Brook; springs within 1000 yards of the canal may be taken for its supply, which is also to be aided by some reservoirs, which were begun in 1796. This company have been authorised to raise 95,000l. the amount of each share being 100l. Mr. John Rennie is the engineer; the eastern part of the canal was begun in 1796, and was said, in 1803, to be nearly done, but it is not yet opened. The western part from the *Andover* canal at Kimbridge was completed to Deane, in October 1798. Stones are to be erected on the banks of this canal, at every $\frac{1}{4}$ of a mile distance.

SOUTHAMPTON WATER. Acts 11 Henry VII. and 15 Henry VIII.—This noble estuary of the Anton and other rivers has a N.W. direction for about 10 miles in Hampshire. The tide flows through its whole length, and through a branch thereof more than 5 miles in length to near Botley; *Southampton water* is navigable for large ships; it commences in the channel between Hampshire and the Isle of Wight at Calshot Castle, and terminates near Red-bridge where it is joined by the Anton river (formerly navigable near 6 miles to Romley), and the *Andover* canal near one of the terminations of the *Southampton* and *Salisbury* canal; near Salisbury it is joined by the *Itchin* river, (about $\frac{3}{4}$ of a mile from the commencement of the *Southampton* and *Salisbury* canal.) In the 4th of Geo. III., an act passed for enlarging and improving the quay and harbour of Southampton, by building a pier and other works which commenced in December 1803, and have since been proceeding.

STAFFORDSHIRE AND WORCESTERSHIRE CANAL. Acts 6, 10, and 30, of Geo. III.—The general direction of this canal (sometimes called the Wolverhampton canal) is nearly north for $46\frac{1}{2}$ miles in the counties of Worcester and Stafford; its middle part is very considerably elevated, and it crosses the grand-ridge without a tunnel; its trade is in the export of coals, pottery-ware, hard wares, &c. is immense, besides the general trade between the *Severn*, the *Mersey*, and *Trent*, which for a long time passed exclusively through it. Near to Stourton, and to Stewponny, it is joined by the *Stourbridge* canal, and at Alderley or Autherley by the Old *Birmingham* canal. Wolverhampton is the 33d British town with 12,565 inhabitants, and Kidderminster is the 95th with 6,110 persons: Dewdley, Stourbridge, Penkridge, and Stafford, are also considerable towns on or near to this canal; which commences in the *Severn* river at Stourport, and terminates in the *Trent* and *Mersey* canal at Great Haywood. From the *Severn* river at Stourport, to the *Stourbridge* canal at Stewponny, 12 $\frac{1}{4}$ miles, is a rise of 127 $\frac{1}{2}$ feet by 13 locks; thence to Tettenhall, the beginning

of the summit-pound, 11 miles, is a rise of 166½ feet by 18 locks; thence to the old *Birmingham* canal, 1¼ mile, is level; thence to Street-way, 8½ miles, is level to the N. end of the summit-pound; thence to the *Trent and Mersey* canal at Haywood, 13¼ miles, is a fall of 100½ feet by 13 locks. This canal is 30 feet wide at top, and 5 feet deep, though the depth of water on the lock-fills is only 4 feet. The locks are 74 feet long and 7 feet wide; and several of them are built of a red kind of free-stone; the boats in general carry 20 tons. At Stourport are two basins belonging to this canal connected with the Severn river by flood-locks to keep the water in them always at one certain height. On this canal are three short tunnels; one is near to Stewponey, the other at Whitlington, and the other is an arched-way under part of the town of Kidderminster; at which place there is an aqueduct-bridge over the Stour river, another at Prestwood on Wordsley brook, another near Milford on the Sow river, and another at Haywood mill over the Trent river. In Chillington is a large reservoir, and at Moseley another, whose waters are conveyed to the summit-pound by feeders of considerable length. This company may make branches to any place within 1000 yards of the line by consent of the land-owners. Mr. *James Brindley* was the engineer to this canal, which he began in September 1766, and finished in 1772. The first lock which this engineer erected was at Crompton, on this canal. This company were authorised to raise 100,000l., the amount of each share being 100l. In September last (1805), the yearly dividend on these was stated to be 24l. The rates of tonnage are stated (in Mr. *John Cary's* excellent work with maps, now publishing in numbers, on *Inland Navigation*), to be 1½d. per ton (24 colb.) per mile on all kinds of articles except lime and lime-stone, which pay only ¾d. per ton; and paving and road materials, and manures for adjoining lands which are to pass toll free on the pounds, and through the locks when the water flows over the lock-weirs. By the *Dudley* act (16 Geo. III.), coals brought from that canal and carried on this may be charged 2d. per ton per mile, but commissioners may authorise lowering this toll. The usual charge made by barge-men in 1796 for freight (including the company's tonnage) was, for perishable goods 2½d. per ton per mile, and for heavy unperishable goods 2d. In 1802, a tunnel 5 feet in diameter and 135 feet long, composed of cylinders of cast-iron, was laid under the river Penk near this canal for draining a morass of 500 acres. In the last sessions (45 Geo. III.) application was made by this company for a new act, to raise the tolls in order to make new locks, the old ones in some places being decayed and nearly worn out, and for making some new rail-way branches. The *Stour* river between Stourport and Stourton, by the side of this canal, was made navigable several years ago, but the works thereon were soon after destroyed by a great flood. In the present month (November 1805), a rail-way branch from Latherford in Sharncliffe is proposed, to Mr. Henry Vernon's collieries in Bushbury.

STAINFORTH AND KEADBY CANAL. Acts 33 and 38 of Geo. III. The general direction of this canal is nearly W.; for 15 miles in the counties of Lincoln and York, it has its course through level fens and is but little elevated above the level of the sea; its objects are the import of coals and export of agricultural produce, with a better drainage of the country through which it passes. Thorne is the only considerable town near this line; which commences in the *Trent* river at Keadby, and terminates in the *Don* river at Fishlake near Stainforth, having also a branch 1 mile in length which joins the *Don* river at Hangman-Hill in Thorne; the whole is on one level, having tide or flood-locks at its ex-

terminities to regulate its height notwithstanding the variable tides and floods in the adjoining rivers. A reservoir of 5 acres is constructed on Thorne Common, and the waste water from this canal is to be discharged into the *Trent*. In 1762, when Mr. *John Smeaton* was consulted about the drainage of Potterick Car, a navigable canal through these fens was in contemplation. This company were authorised to raise 54,200l., the amount of shares being 100l. each.

STOKE RIVER. The direction of this river (sometimes called the *Winton*) is W. for about 8½ miles in the county of Norfolk; it is embanked nearly its whole length through the fens, and is but very little above the sea; its objects are the import of coals, deals, &c. and the export of agricultural products. Downham is the only considerable town near it; it commences in the Great *Ouse* river between Denversluice and Salters-Load, and terminates at Stoke-Ferry near the town of Stoke.

STORT RIVER. The general direction of this river is almost N.E. by a bending course of about 13 miles between the counties of Essex and Hertford; its northern extremity is considerably elevated; its objects are the import of coals, deals, &c. and the export of farming products. Hoddesdon and Bishopstortford are considerable towns near this river; which commences in the *Lea* river near Hoddesdon, and terminates at Bishopstortford. In 1785, this navigation was proposed to be joined at its northern end by the *Bishopstortford* and *Cambridge*, and in 1789, it was intended to join the *Bishopstortford* and *Wilton* at the same place.

STOUR RIVER (Christchurch.) The direction of this river is nearly N.W. for about 35 miles in the counties of Hants and Dorset; its northern end is considerably elevated; its objects are the import of coals, deals, &c. and the export of farming products; Christchurch, Wimbourn-Minster, Blandford-Forum, and Sturminster-Newton, are considerable towns on this river; which commences in the tide-way in Christchurch-bay at Christchurch-harbour, and terminates at the town of Sturminster. At Gainscross in Shillington-Okeford, it is to be joined by the *Dorset* and *Somerfet* canal. In 1762, Mr. *John Smeaton* was consulted on the intended improvements in Christchurch-harbour; the spring-tides in this harbour flow only 5 to 7 feet, and the neap-tides no more than 4 to 6 feet; and 3 hours after high water there is a second or smaller tide, which flows in the harbour from 8 to 18 inches, being greatest at the neap-tides. In the reign of Charles II., a pier of 256 yards in length, was constructed of lumps of iron-stone out of the loose sandy-cliff near it, and Mr. *Smeaton*, in 1764, planned another pier to be built for the better security of this harbour.

STOUR RIVER (Harwich.) The general direction of this river is nearly W. by a bending course for about 29 miles between the counties of Essex and Suffolk; the first 10 miles is a wide estuary through which the tide flows, the western end is not greatly elevated; its objects are the import of coals, deals, &c. and the export of farming products; Harwich, Manningtree, Neyland, and Sudbury, are considerable towns on this river; which commences in the *Stowmarket* and *Ipswich* navigation (near its junction with the German Ocean) at Harwich, and terminates at Sudbury.

STOUR RIVER (Sandwich.) Act 7 Henry VII.—The general direction of this river is nearly W. by a crooked course of about 18 miles in the county of Kent; it is but little elevated above the sea in any part; its objects are the supply and trade of Canterbury, and the export of farming products. Canterbury is the 57th British town with a population of 9,000 persons, and Sandwich is the 93d with 6,506 persons, Ramsgate is also a considerable place near to this river; which commences in the English Channel or

Downs at Sandwich Haven ($1\frac{1}{2}$ mile from Ramsgate-harbour), and terminates at the city of Canterbury; the lower end of this river, for $1\frac{1}{2}$ mile in Pegwell bay, has its course through shifting sands which are dry at low water, and covered at high water; it is therefore unsuited for large vessels to enter, and *Ramsgate harbour* is the only secure retreat for ships in case of a storm on this part of the coast. The celebrated piers which form this harbour were begun in 1749; the southern pier extends 800 feet eastward into the sea, it then returns northward, forming the front next the Downs, by a polygon of 5 sides, each 450 feet in length; these are joined at their angles by octagons of solid masonry that are 60 feet across; the breadth of the pier at top including the parapet is 26 feet, and the whole is built of hewn Portland and Purbeck stone. The entrance for ships is from the north nearly, and is 200 feet wide, having a light-house with Argand's reflecting lamps on its west head, and this is connected with the shore by a similar, though short pier, as on the southern side. The area of the famous harbour, thus formed in the open sea, is 46 acres, and it is deep enough to receive ships of 4 or 500 tons burthen. A spacious dry-dock for the repair of ships connects with this harbour. In a few years after the piers were completed, this harbour was nearly choked with mud deposited by the tides. Mr. *John Smeaton*, who was consulted, erected a cross-wall at the uppermost extremity of the harbour with numerous sluices therein, by the drawing of which, after the tide has retired and left this reservoir full of water, the mud has been since effectually scoured out; this excellent engineer also extended the pier 400 feet at the head. Nearly 500 ships have been known at once to assemble in this harbour for shelter on the approach of a storm. An act 5 Geo. III., passed for improving this harbour as above, and by 37 Geo. III. the tonnage charged on vessels passing the English Channel for the support of Rye-harbour, was transferred to this harbour as before mentioned. In the years 1802 and 1804, the *Canterbury and Nicholas-bay* canal was intended to join the *Stour* river at Canterbury; and in 1802, the *Melway and Rother* canal was proposed to join it near the same place.

Stour River (Stourbridge.) Many years ago the *Stour* river from the *Severn* at Stour-port to the town of Stourbridge, (passing the town of Kidderminster,) about 14 miles, was made navigable by means of sluices, weirs, and other works; but soon after there happened so sudden and violent a flood as to destroy all these works. The *Stafford and Worcester*, and the *Stourbridge* canals, have since supplied more effectually the place of this river navigation.

STOURBRIDGE CANAL. Acts 10 and 22d of Geo. III. The general direction of this canal is nearly E. by a crooked course of about 5 miles in the county of Stafford; its eastern end is considerably elevated, and extends within about 3 miles of the grand-ridge on its eastern side; its objects are the export of coals, iron-stone, &c. and forming part of the communication between the Old *Birmingham* and the *Severn*, &c. Stourbridge and Dudley are considerable towns near this line; which commences in the *Staffordshire and Worcester* canal near Stourton and Stewponey, and terminates in the *Dudley* canal at Black-Delph; there is a branch of near 1 mile to the town of Stourbridge, and a branch of 2 miles to Pensnett-Chase reservoir, with a side-branch thereto of near $\frac{3}{4}$ of a mile in Brierly parish. From the *Stafford and Worcester* canal to near Stewponey, $\frac{3}{4}$ of a mile, is a rise of 43 $\frac{1}{2}$ feet by 4 locks; thence to the Stourbridge branch, 2 miles, is level; thence to the Lays, $1\frac{1}{4}$ mile, has a rise of 148 feet by 16 locks; thence to the *Dudley* canal, $1\frac{1}{2}$ mile, is level; the Pensnett and Brierly branches are level with the last or summit-pound, and the Stourbridge branch is level. The

width of this canal is 28 feet, and the depth of water 5 feet. The Pensnett-Chase or Fen reservoir is 12 acres in extent, for supplying the head-level of this canal. This company were at first authorized to raise 30,000l. in 100l. shares; the last act authorized calling upon the subscribers for 7,500l. more, by which their shares are now increased to 125l. each. The rates of tonnage will be found in Mr. *John Cary's Inland Navigation*, pages 50 and 51. Goods may be navigated on the summit-level toll free; and road-materials and manures for adjoining lands, may also be carried on any of the pounds toll free. Less than 15 tons are not to pass any lock without consent. Side-branches may be made to the adjacent collieries. The *Worcester and Birmingham* company were bound (act 31 Geo. III.) to make up the profits of this concern to 9 per cent per annum, in case of their canal lessening the trade hereon; but on the extension of the *Dudley* canal to join the *Worcester and Birmingham*, the last mentioned company were exonerated therefrom, and the *Dudley* engaged (33 Geo. III.) to make up the annual dividend on the shares in this concern to 12l. each; but not to exceed 3l., and this when their own canal yielded a dividend of 5l. per share. The part of this canal below Stourbridge supplies the place of the river *Stour* navigation, which was destroyed by floods as above mentioned. In 1786, the *Stourbridge and Worcester* was proposed to join this canal at Stourbridge; as was also a branch since proposed from the *Worcester and Birmingham*.

Stourbridge and Worcester. In 1786, a canal was proposed, and supported by the late lord *Dudley and Ward*, from the *Severn* river at Diglis below Worcester city to the *Stourbridge* canal at that place, passing Bromsgrove; its proposed length was 26 miles with 772 feet of lockage, by 128 locks; some tunnels and other large works were necessary; a bill for this canal passed the commons, but was rejected by the house of lords.

STOVER CANAL. Act 32 Geo. III.—The general direction of this canal is nearly N.W. for $6\frac{1}{2}$ miles in the county of Devon; it is but little elevated; its objects are the import of coals, shelly sea-sand and lime, as manures, and the export of potters' clay (used in Staffordshire, Lancashire, &c.) and a peculiar kind of imperfect coal found in small quantities at Bovey-Tracey; Newton Bushel and Chudleigh are considerable towns near this canal, which commences in the tide-way in the *Teign* river at Newton Abbots, and terminates at Bovey-Tracey, with a branch of $5\frac{1}{2}$ miles to the town of Chudleigh. From Newton-Abbots to Newton-Bushel, 1 mile, is a rise of 20 feet; thence to Bovey, $5\frac{1}{2}$ miles, is 30 feet rise; the Chudleigh branch is level. *James Templer*, esq. is the sole proprietor of this canal, and Mr. *Gray* was his engineer. At Teigngrace, and the adjoining parishes, the surplus water of this canal has been applied to the irrigating of the lands below it, a capital improvement, which we are very anxious to see more generally adopted.

Stowmarket and Bury Rail-way. In December, 1802, it was in contemplation to make a rail-way from the *Stowmarket and Ipswich* navigation at Stowmarket, to the *Lark* river at Bury St. Edmunds, for the purpose of supplying the latter place, and the intermediate country with coals; (the *Lark* navigation being often interrupted by droughts in the autumn;) and for the readier export of farming products.

STOWMARKET AND IPSWICH NAVIGATION. Acts 33 and 45 Geo. III.—The general direction of this navigation (which follows the course of the *Orwell* river) is nearly N.W. for about 26 miles, in the county of Suffolk, the first 13 miles, to near Ipswich, being a wide channel or estuary in the tide-way, the remainder is not greatly elevated; its objects are the import of coals, deals, &c. and the export of

farming products; it is joined by the *Stour* river near Harwich. Ipswich is the 41st British town, with a population of 11,277 persons. Harwich, Needham, and Stowmarket are also considerable towns near this navigation; which commences in the German ocean at Landguard fort, and terminates at the town of Stowmarket. This company were, by an act prior to the above, authorized to raise 14,300*l.* by the first act above 15,000*l.* more might be raised; the last act was for improving the port of Ipswich by deepening the same, so that ships might unload at the wharfs, &c. In December, 1802, it was proposed that the *Stowmarket and Bury* rail-way should join this navigation at Stowmarket.

STRATFORD CANAL. Acts 33, 35, and 39 Geo. III.—The general direction of this canal is nearly N. for 23½ miles, in the counties of Warwick and Worcester; it is very considerably elevated, and crosses the grand-ridge; its objects are the export of coals, lime, and paving-stones, and as a link in the great chain of canal communication; at Kingwood in Rowington a branch of this canal connects with the Warwick and Birmingham: Stratford-upon-Avon and Henley are considerable towns on or near this canal, which commences in or near the *Avon* river at Stratford, and terminates in the *Worcester and Birmingham* canal at King's Norton, about 6 miles from Birmingham. From near Hockley there is a branch 2½ miles long to Tanworth quarries; from near Lapworth there is another branch of 1½ miles to the *Warwick and Birmingham* canal; and from near Wilmcote is a branch of 4 miles to Temple-Grafton lime-works, with a branch of about 1 mile from this cut to Aston-Cantelow. From Stratford to near Copnas-hill, 1½ mile, is level; thence to Wilmcote, 1 mile, has a rise of 86 feet; thence to Preston-mill, 6 miles, is level; thence to Preston-green, 1½ mile, is a rise of 76 feet; thence to Lapworth-hall, 1 mile, is level; thence to Hockley Heath, 2½ miles, is a rise of 147 feet; and thence to the *Worcester and Birmingham* canal, 10 miles, is level; the Tanworth branch is level, and connects with the summit-pound: the Temple-Grafton cut is level for the first 2½ miles, and in the next 1½ mile the rise is 20 feet. Near Milepole hill is a tunnel of 320 yards in length; there are several small aqueduct bridges; and some deep-cutting near Waring's Green. In May 1796 the summit-level of this canal from the *Worcester and Birmingham* canal to Hockley-heath was completed and opened. This company was authorized to raise 225,000*l.* the amount of shares 100*l.* The rates of tonnage and exemptions are very long; see *Phillips's 4to. History, Appendix*, p. 111 and 112. At the junction with the *Worcester and Birmingham* canal stop-gates are to be erected, to be shut and locked by either company, when the supplies of the other canal fail in dry seasons; with the *Dudley and Worcester and Birmingham* canals there are a number of regulations as to tonnage, in the second act above (35 Geo. III.). About the year 1792 the *Stratford and Croperdy* canal was proposed to join this at Stratford.

Stratford and Croperdy. About the year 1792 a canal was proposed to connect with the *Avon* river and *Stratford* canal at Stratford, and proceed to the *Oxford* canal at Croperdy, by a course of about 31 miles in length; this being the southern part of the proposed line between *Dudley* and *Croperdy*; the northern part thereof being since occupied by the *Stratford* and the *Dudley* canals.

STROUDWATER CANAL. Acts 34 Geo. II. 15 Geo. III. 23 (for *Thames and Severn*.) and 33 and 37 Geo. III. (for *Gloucester and Berkley*).—The general direction of this canal is about E. for 8 miles, (following nearly the course of *Stroudwater* river,) in the county of Gloucester; it is not elevated; its objects are the import of coals, and being part of the first direct communication between the

Severn and *Thames* and *Ifis* rivers; at Wheatenhurst the *Gloucester* and *Berkley* canal crosses and connects herewith. Stroud is the 114th British town, with a population of 5,422 persons. This canal commences in the *Severn* river at Framiload, and terminates in the *Thames* and *Severn* canal at Wallbridge near Stroud; from the *Severn* to the *Thames* and *Severn*, there being a rise of 108 feet: this canal is wide enough for the *Severn* river boats. The engineers were Mr. *Thomas Toman* and Mr. *Robert Whitworth*. The first of the above acts was for powers to raise 20,000*l.* in 200*l.* shares, intending to execute the works under the powers of an act of 2 Geo. II. for improving the *Stroudwater* river, but several expensive law-suits put a stop to the works, as we have already mentioned, until the second act was obtained: a double lock of 14 feet rise on this canal had a slipping bank of earth 20 feet high by its side, and gave immense trouble, to prevent the walls thereof being bulged in, this was at last accomplished by the turning of two dry drains of four feet diameter, between the lock and the bank. In 1802 the dividends on shares in this concern were 6*l.* each, and their price was about 22*5l.* This canal has no horse towing-path, but slides are erected thereon, and the barges are hauled by men. Where this canal crosses the *Gloucester* and *Berkley*, stop-gates are to be erected to prevent this canal from losing its water; no dues are to be taken for vessels crossing either of these canals. If, while the *Gloucester* and *Berkley* is cutting, the navigation of this canal is interrupted, five guineas per day are to be paid to this company; vessels passing to or from the *Berkley* and *Gloucester* canal and this, are to pay the same tonnage as to and from the *Severn* at Framiload. This company are authorized to take 2*s.* 3*d.* per ton for coals which pass through this canal, and on the *Thames* and *Severn* canals, but not beyond Brinscomb bridge thereon, and for such coals as pass eastward of Brinscomb bridge, 1*s.* per ton.

Stroudwater River. The act of 2 Geo. II. passed for making this river navigable between the *Severn* and the town of Stroud, a distance of about 8 miles, as above; but the opposition of the millers and others prevented its being accomplished, until 34 Geo. II. when Mr. *Bridge* undertook to construct the navigation, without waste of water or prejudice to the mills, by means of cranes to hoist the goods in boxes out of the boats in one pound, and place them in others in the adjoining pounds, as we have before described; but this scheme miscarried, and the projectors were nearly ruined: at length the *Stroudwater* canal was constructed by the side of this river as above.

SURREY IRON RAIL-WAY, (Northern part). Acts 41 and 45 Geo. III.—This, the first public rail-way constructed near the metropolis, has about a S.E. direction, for 10 miles, in the county of Surrey: its southern end has a considerable elevation: its objects are the import of coals and manures, and the export of chalk, flint, fire-stone, fullers'-earth, and agricultural products. Croydon is the 108th British town, with a population of 5703 persons; Wandsworth is also a considerable town on this line; which commences near the tide-way in the river *Thames* at Wandsworth, and terminates at the turnpike-house S. of Croydon, in the southern part of the *Surrey iron-rail-way*; at the N.W. extremity of Croydon the line of this rail-way is but about ¼ of a mile from the *Croydon* canal; from Mitcham common a branch goes off for about 1½ mile to Mr. *Shipley's* skinning mill at Carshalton; and, to Messrs. *Werre* and *Burth's* oil-mill, about ¼ of a mile, there is another branch at Garrat-lane. This rail-way has nowhere a greater ascent than about 1 inch in 10 feet: it is double throughout, with numerous crossing places for the carriage out of one road or track into the

other; of these we have already given a particular account, as also of the contrivances for shooting the contents of the railway waggons, on some occasions, into barges lying in the entrance basin at Wandsworth, which is about $\frac{1}{4}$ of a mile long, with a lock next the *Thames*, and is spacious enough to hold 30 barges or more at once, several of which can lie along the wharf to load or unload at the same time. The width of each track is about $5\frac{1}{2}$ feet, the waggons carry about $3\frac{1}{2}$ tons each, and several of them are often linked together to be drawn by one horse. This rail-way crosses the Wandle river twice on wooden bridges. On the 9th of January, 1802, the entrance basin at Wandsworth was completed and opened; in October of the same year, the rail-way from the side thereof crossing the turnpike road, and extending to Garrat was completed, and in the course of the present year it was opened to Croydon. The company were, by the first act, authorised to raise 50,000*l.* and a further sum, by the act of the late sessions, the amount of shares 100*l.* Few subjects have been more variably stated than the cost per mile of this rail-way. Mr. *John Phillips*, after noticing in his *History* the commencement of this work, adds, that iron rail-ways are made at an expence of about 300*l.* per mile. The original estimate was, we believe, 2000*l.* per mile; at a public meeting at Gosport, in September 1803, it was stated by some favourers of the extension of a canal from Croydon to Portsmouth, that the expenditure on this rail-way had amounted to 6,400*l.* per mile; but the advocates for extending this rail-way to Portsmouth instead of a canal, then contended that the expence did not exceed 4,500*l.* per mile; while Mr. *James Malcolm*, in his *Agricultural Report on Surrey*, just published, after stating the great pains he had been at to come at the facts, says, "instead, therefore, of the expence being 2000*l.* per mile, it appears as if it would be 7000*l.*" (this includes all the expenditure of the company). The rates of tonnage are from 2*d.* to 6*d.* per ton, per mile, for different goods; and owners of adjoining lands may use the rail-way as a drift road. Ten pounds annually are to be paid to the city of London by this company, for connecting with the river *Thames*.

SURREY IRON RAIL-WAY (*Southern part*). Act 43 Geo. III.—The general direction of this line of rail-way is nearly S. by a bending course of about 16 miles, in the county of Surrey; upon the chalk-hills or North Downs, it is greatly elevated; its objects are the import of coals and manures, and the export of chalk, lime, fire-stone, free-stone, flints, fullers'-earth, and agricultural products. Croydon is the 108th British town, with a population of 5,743 persons; Ryegate and Godstone are also considerable towns on or near this line, which commences in the northern part of the *Surrey iron rail-way* at Croydon turnpike, near the southern end of that town, and terminates at Godstone, passing near to the towns of Merstham and Ryegate in its course. It has a rise or fall of 1 inch in 10 feet, in crossing the Downs: near to Merstham is a considerable length of cutting 30 feet deep in some places, in order to obtain the proper descent; at Smitham-bottom is an embankment of 20 feet high, across a valley, for the same purpose, with a road-arch under it; it crosses the Croydon and Merstham road in another place by an arch, and the road is sunk considerably in order that the rail-way with its proper descent may pass over it. The width of this double rail-way, including a path on each side for the carriage drivers is 24 feet. Some of the waggons hereon have their fore-wheels placed quite forward, and the hind-wheels nearly under the middle of the waggon, by which means stones, &c. can easily be shot out of them when required. Near to this rail-way at Merstham there is a quarry of white soft free-

stone (much similar to the Totternhoe-stone on the *Grand Junction* summit branch). The shares in this concern are 100*l.* each. In September, 1801, it was in contemplation to make a branch of this intended rail-way from near Ryegate to the *Arun* river at Wilborough green; and another branch or rather an extension hereof, from near Godstone to the *Ouse* upper navigation at Linfield. About the month of June last (1805,) this rail-way between Croydon and Merstham was opened, and 12 waggons loaded with stone, weighing $38\frac{1}{2}$ tons, were drawn with ease by one horse for 6 miles down the descent to Croydon-turnpike, in 1 hour and 41 minutes; from which place the same horse set off again with 4 other loaded waggons attached, and persons riding on them, making in the whole more than 55 tons, which it was said he drew with apparent ease!

SWALE RIVER. The general direction of this river is nearly N.W. for about 35 miles, by a crooked course in the North Riding of Yorkshire. Its northern end is very considerably elevated, and this river is subject to rapid and almost uncontrollable floods: its objects are the carriage of coals, and the export of farming products. Aldborough and Richmond are considerable towns near, or on this river, which commences in the *Tore* river at Myton; and the navigation was intended to terminate at Richmond. In 1767, Mr. *John Smeaton* was consulted on the propriety of moving Topcliff mill to a new site, in the design which the proprietors of this navigation had adopted of building new mills in several places, and on which it has been said that 30,000*l.* was expended, and but a small part of the above line was rendered effectually navigable. Mr. *John Smith jun.* was the resident engineer. In 1801, the *Topcliff and Pierbridge* was proposed to join at Topcliff.

SWANSEA CANAL. Act 34 Geo. III.—The direction of this canal is about N.N.E. for $17\frac{1}{2}$ miles in the counties of Glamorgan and Brecknock, in South Wales. Its northern end is considerably elevated: its objects are the export of coals and iron-stone, iron, &c. the carriage of lime to the intermediate works and country; and copper-ore, to the works, &c. Swansea is the 99th British town, with 6,099 inhabitants. This canal commences in Swansea harbour, in Swansea bay, at the mouth of the Tawe river, and terminates at Hen-nyodd lime-works: a part of this line between Llandoer brook and Morris town, $1\frac{1}{2}$ mile in length, (called *Morris's canal*) through the estate of the *duke of Beaufort*, was constructed by that nobleman, who receives the tolls thereof. From near Swansea to Llanfawlet is a branch of 3 miles in length; and a rail-way branch of about 2 miles to a large coal mine, where an audit or tunnel of 3 miles in length has been made under ground, and out of which 200 tons of coals are daily brought; on an inclined-plane on this branch, near 1 mile in length, the coal-waggons descend without horses, regulated by a convoy or brake, as we have before described, and the empty waggons are drawn up the plane again by horses. From the tide-way at Swansea to opposite Pont-ar-Taw, $8\frac{1}{2}$ miles, is a rise of 105 feet; thence to Pont Gwaynclawdd, 8 miles, is a rise of 230 feet; and thence $\frac{1}{4}$ of a mile to Hen-nyodd is a rise of 31 feet. An act 44 Geo. III. passed for amending two former ones, for building piers, and deepening and improving the harbour of Swansea, under the direction of captain *Joseph Hudlart*. About the year 1797 the western pier, extending 228 yards into the sea, was completed; which had the effect of confining the current of the Tawe river, and deepening the mouth of the harbour 2 feet: in 1802 this pier was extended 57 yards farther out, and in November 1804 a jetty thereto was completed. In April last (1805) a new pier was begun on the eastern side of the

harbour, which is to be extended out and brought round westwardly, within 70 yards of the other pier, for effectually securing and scouring the mouth of the harbour: dry and wet docks are also intended, and by embanking the river, a most spacious quay is to be formed. From this port, in 1768, only 694 ships cleared out; in 1790 these were increased to 1677 ships, and in 1800 to no less than 2590 of 134,264 registered tons. Within 2 miles of Swansea, seven large copper-works have of late years been erected, for smelting of roasted ore from the Cornish and Anglesea mines, brought in ships, which return laden with coals for working the mine-engines and roasting the ore: the number of iron-furnaces, potteries, and other large works near this place are also considerable. This canal company was authorised to raise 90,000l., the amount of shares 100l. each; and it was provided in the act, that this canal should be completed in 4 years; several rail-way branches may be made thereto. The engineer was Mr. Thomas Sheafly, and the canal was completed and opened in October 1798. The rates of tonnage may be seen in *Phillips's 4to. History, Appen.* pages 166 and 167. Boats with less than 15 tons, when the water does, and 10 when it does not flow over the lock-weirs, are not to pass without leave or paying for that tonnage. In the year 1804, 54,235 tons of coal and culver were brought down this canal for exportation, and the gross tonnage on this canal amounted to 3590l. In Swansea harbour, the *Swansea and Oystermouth* rail-way connects with this canal.

SWANSEA AND OYSTERMOUTH RAIL-WAY. Act 44 Geo. III.—The general direction of this rail-way is nearly S.W. by a bending course, following closely the sea shore, for about $7\frac{1}{2}$ miles in length in the county of Glamorgan, in South Wales: its object is the carrying of lime-stone, lime, and coals. Swansea is the 99th British town, with 6,099 inhabitants. This rail-way connects with the *Swansea* canal in Swansea harbour, and proceeds thence to the Mumbles lime-stone quarries near Oystermouth. In April last (1805) this rail-way was nearly completed. There is a light-house on the Mumbles point for the security of ships entering Swansea harbour, which was lately improved.

TAMAR MANURE NAVIGATION. Act 36 Geo. III.—The general direction of this canal is nearly N.W. for about 22 miles, following the course of the Tamar river, on the southern coast of the counties of Devon and Cornwall. Its northern end is considerably elevated: its objects are the import of coals, and sea-sand and lime as manures; and the export of agricultural products. Launceston is the only considerable town on this line; which commences in the tide-way in the *Tamar* river at Morwellham quay (the commencement of the *Tavistock* canal) near Callstock, and terminates at Tamarton bridge in North Tamarton, with a branch to Rich-mill grove in Launceston. The *Tamar* is to be made navigable as far as Port-pool near Blanch-Down, before the canal commences. The locks are to be either about 5 feet or $9\frac{3}{4}$ feet wide, and $12\frac{1}{2}$, $24\frac{1}{2}$, or $36\frac{1}{2}$ feet long, in order to receive a number of small boats, in length and side by side therein, as may be judged best. Inclined planes and rail-ways may be substituted in place of locks on the canal in any part. This company is authorised to raise 121,000l., the amount of each share 50l. A feeder may be taken from the Tamar river, and all springs within 2000 yards of the head level, and within 1000 yards of every other part of the line; 200l. per annum is to be paid by this company to the duchy of Cornwall, for the liberty of making this navigation. We have not been able to learn what progress has yet been made in the cutting of this canal. By the act 14 Geo. III. a

canal was intended, but never executed, through this line, and extending to the Irish Channel, called the *Bude and Launceston* canal.

TAMAR RIVER. The general direction of this river is nearly north by a crooked course of about 6 miles, between the counties of Devon and Cornwall; the tide flows through its whole length; Beer-Astton is a considerable town near this navigation; which is used for the import of coals, sea-sand, lime, &c. and the export of slate and agricultural products. It commences in *Hamoaze* and terminates in the *Tamar Manure* navigation and *Tavistock* canal, at Morwellham quay near Callstock. In the year 1774, an act passed for the *Bude and Launceston* canal intended to connect with this at Callstock, but it was never carried into execution.

Tarbeth Canal. In 1773, Mr. Watt surveyed the isthmus between East and West *Tarbeth* lochs, on the west coast of Scotland, for a canal to communicate between *Loch Fine* and the sound of *Jura*; the distance of high-water mark in the two lochs he found to be 1 mile, and the height of the ridge between them, 45 feet above high-water at neap tides. Mr. Watt's different estimates were, for a canal with locks 7 feet deep, 17,988l.; and for one 10 feet deep and a proportional width, 23,884l. The expenses of a thorough cut without locks, of 12 feet deep at high-water, 73,840l., and for one of 15 feet deep, 120,789l. A very large canal has since been formed about 13 miles north of this, called the *Crinan* canal, which more effectually answers the purpose of communication between *Loch Fine* and the sound of *Jura*.

TAVISTOCK CANAL. Act 43 Geo. III.—The general direction of this canal is N.E. for about $4\frac{1}{2}$ miles in the county of Devon; great part of it is considerably elevated above the level of the sea: its objects are the export of slate, copper-ore, and other minerals, and of agricultural products; the import of coals, lime, and other articles for the supply of Tavistock town and the surrounding country; and to facilitate the working of the mines in Morwellham down: this canal commences in the tide-way in *Tamar* river (near the commencement of the *Tamar Manure* navigation) at Morwellham quay new basin, near Callstock, and terminates at the town of Tavistock. From Crebar near the north end of the tunnel, it has a branch of 2 miles to the slate quarries at Mill-hill bridge. From the *Tamar* river, $\frac{1}{4}$ of a mile is level with high water at Morwellham quay; thence in $\frac{1}{4}$ of a mile, is a rise of 237 feet; thence, about $3\frac{1}{4}$ miles to Tavistock is level; the branch is level to New Quarry, about $1\frac{1}{2}$ miles; thence to Mill-hill bridge, $\frac{1}{2}$ of a mile, is a rise of 194 feet. The locks upon this canal are to be calculated in length and width for the use of boats of $12\frac{1}{2}$ feet long, and 5 feet wide, either singly or several together, as on the *Tamar Manure* navigation above mentioned: but the company have the power to erect inclined-planes for boats, or boxes of goods, instead of locks, if they think fit. Through Morwellham down, which is of hard rock, and supposed to be intersected by several fissures, or loads filled with metallic ores, is to be a tunnel about 2500 yards long, and about 460 feet beneath the highest point of the down in its course: near Crebar is to be an embankment and aqueduct bridge 60 feet high, across the Lumbourn river; which is to have a new course cut for it for a considerable distance near the branch of this canal below New Quarry. This canal is to be fed from the *Tavy* river at Tavistock, and by any springs or streams within 5000 yards of the line. Mr. John Taylor is the engineer to this canal and tunnel, which passes entirely through the estate of the *duke of Bedford*, who has leased to this company the mines which may be found in the tunnelling, or within certain distances of this canal. In February last

(1805) about 300 yards in length of the tunnel had been cut, and a known load of copper-ore had been interdicted therein, which gave the best hopes of discovering other unknown ones, as the work proceeds. This company is authorised to raise 50,000*l.*, and the amount of each share is 50*l.* The rates of tonnage are for lime-stone conveyed through the tunnel, 1*s.* 3*d.* per ton; for building-stone, slates, bricks, tiles, clay, sand, earth, dung, ores, iron, and metals (made marketable) conveyed through the tunnel, 2*s.* per ton; and for coals, coke, culm, lime, timber, bark, corn, grain, and all other goods passing through the tunnel, 3*s.* per ton; building-stone, slate, &c. as above, carried on the whole, or any part of this canal, or its branches, except in the tunnel, 1*s.* per ton; and coals, coke, &c. 1*s.* 6*d.* per ton. The last rates are not to be charged on any goods either carried or subsequently removed on any part of this canal, which have before paid the tunnel rates: and ores may be carried to the dressing-floors, or the waste or rubbish of mines or loads be removed to proper places on any part of this canal or its branches, free of tolls. Besides the above rates, all goods which pass into, or from the *Tamar* river, and are not loaded at Morwellham quay, are to pay as follows for reimbursing the owner and occupiers thereof, for the loss of wharfage on such goods, viz. slate 3*d.* per ton, lime-stone 6*d.* per ton; ores, (made marketable) iron, bricks, tiles, clay, sand, earth, and dung, 6*d.*; and all other goods 1*s.* per ton; and over and above this, one penny per ton is to be paid on all goods entering the canal basin at Morwellham. The *duke of Bedford* may make collateral branches or rail-ways to this canal in any part.

TAVY RIVER. The general direction of this river is N.E. for about 2½ miles in the county of Devon; the tide from the south coast flows through its whole length: its objects are the import of coals, sea-sand, &c. and the export of slate, copper-ore, &c. It commences in *Hamoaze* and terminates at Lophill quay.

TAW RIVER. The direction of this river, or estuary, is nearly east for about 8 miles on the north-west coast of Devonshire; the tide flows through its whole length: its objects are the supply of Barnstaple and the adjacent country with coals and other articles, and the export of farming products. This navigation commences in *St. George's Channel*, at Biddeford bay, and terminates at the town of Barnstaple: near to Appledore the *Torrige* river joins this navigation.

TAY RIVER. The general direction of this river, firth, or estuary, is nearly west for about 26 miles, between Angus and Fife, and in the county of Perth in Scotland. The tide flows through its whole length: its objects are the supply and trade of Dundee and Perth, and the adjacent country. Dundee is the 18th British town, with 26,084 persons, and Perth the 26th, with 14,878 persons. This firth commences in the German Ocean, and terminates at Perth bridge. This bridge, built of stone by *Mr. John Mylne*, was swept away by a rapid flood in 1621. In 1763, *Mr. John Smeaton* was consulted on the building of a new bridge; and in 1766 he began one of 7 arches, where the river was 893 feet wide: the depth of the Tay at this bridge at neap tides in dry seasons was only 2 feet, at spring tides 10 feet deep. At Stanley, 7 or 8 miles higher up this river, three foughs or tunnels of considerable length (one of them from 12 to 9 feet wide arched with stone) are driven through the hill, which occasions a great loop in the river, by which 24 to 20 feet fall is gained, for a large portion of the stream, to work cotton-mills and other machinery; and running in this subterraneous channel it never freezes.

TEES RIVER. The general direction of this river is nearly S.E. by a crooked course of about 12 miles, between the counties of York and Durham: the first four miles are by a very wide estuary: the tide flows through its whole length: its objects are the trade of Stockton, and the export of agricultural products. Stockton is a considerable town on this river; which commences in the German ocean, at Seaton Nook, and extends to the town of Stockton. In the present autumn there was an intention of improving this navigation. In 1803, the foundations were laid for an iron-bridge, to be erected under the direction of *Mr. Thomas Wilson*, over this river at Yarm, a few miles above Stockton, in place of an old stone bridge, whose clumsy piers had long obstructed the current, and occasioned the river frequently to overflow its banks. In 1768, the *Winston and Stockton* canal was proposed for extending this navigation westward to the coal district about Winstan.

TEIGN RIVER. The direction of this river, or estuary, is west for about 4½ miles in the south-eastern coast of Devonshire: the tide flows through its whole length: its objects are the import of Newcastle or Welsh coals, and the export of potters' clay, hovey-coal, and agricultural products: it commences in the English channel, and terminates at Newton-Abbots, at the commencement of the *Stover* canal, near to Newton-Bushel.

Ternbridge and Winsford. In 1765, *Mr. Whitworth* proposed a canal from the *Severn* river at Ternbridge below Shrewsbury, to the *Weaver* navigation at Winsford, 6½ miles, in the counties of Salop, Stafford, and Chester, with a branch therefrom, near Bridgeford; 43 miles, to the *Trent* river at Wilden-Ferry. From the *Severn* to the summit or grand-ridge (requiring 25 feet deep cutting,) below Offley-Park, 24 miles, is a rise of 156½ feet; thence to the *Trent* branch, (1¼ mile below Bridgeford,) 7½ miles, is a fall of 543 feet; thence to the summit or grand-ridge again, (requiring 25 feet deep-cutting,) in Madeley park, 10½ miles, is a rise of 800½ feet; thence to the *Weaver* navigation, 22½ miles, is a fall of 284 feet: the branch from Bridgeford to the *Trent* has a fall of 209½ feet. The course of this canal is by Wansford, Allcot, Crudgington, Chetwin-park, Batchacre-Grange, Eccleshall, Standon, Wyburnbury, and Barton-crofts, near Nantwich. The branch is conducted by Stafford, Tixall, and thence following within a small distance the course of the *Trent* river. This canal was proposed to be 27 feet wide at top, 18 at bottom, and 5 feet deep, with a towing path on both sides; the locks 60 feet long and 13 wide, and about 10 feet rise each: the boats of 50 tons burthen: 78 road bridges, and 25 accommodation bridges were thought necessary, and 162 aqueducts and culverts: the estimated expence was 99,800*l.* The *Staffordshire and Worcester* and the *Trent and Mersey* canals, which were adopted in the following year, embrace all the general objects of this canal. The *Sandbach*, and the *Newport and Stone*, have since been proposed to occupy parts of the south-western end of this line, but, like this, were over-ruled.

THAMES RIVER, (lower part). Acts 19, 29, 39, 42, 43, 44, and 45 of Geo. III.—This fine river, by far the most important for trade, not only in Britain but in the whole world, has its career nearly west for about 72 miles between the counties of Kent and Essex, and Surry and Middlesex. The first 20 miles is by an exceeding wide estuary; the next 21 miles is still an estuary of considerable width; the remaining 31 miles is crooked, and gradually diminishing: the tide flows very powerfully through its whole length. To enumerate its objects would be to recount almost every species of trade and commerce which is carried on in

Europe. At East Mersey it connects with the *Colne* river; at West Mersey, with *Blackwater* river; at Foulness east point, with *Crouch* river; at Whitstable and at Sheerness, with the *Medway* river; at Gravesend, with the *Thames and Medway* canal; opposite to Purfleet, with the *Darent* river, or Dartford creek; at Bow-Creek, with the *Lea* river; at Blackwall and at Limehouse-hole, with the *Isle of Dogs canal*, (a new side-cut for shortening the navigation of this river); at Greenland-dock, and at Wilkinson's gun wharf, Rotherhithe, with the *Grand Surry* canal; and, at Limehouse, with the *Limehouse* canal. London, the first British town, has a population of 864,845 persons; Greenwich is the 31st, with 14,339 persons; and Woolwich is the 53d, with 9,826 persons; Margate, Faversham, Milton, Queenborough, Sheerness, Leigh, Gravesend, Grays-Thurrock, and Deptford, are also considerable towns on or near this lower part of the *Thames* river; which commences in the English channel at East Ness near Margate, and terminates in the *Thames*, middle part, at London-bridge. Large ships of war can come up to Deptford, and merchants' ships of 7 to 800 tons burthen frequently lie at the keys close to London-bridge. The port of London, or part wherein the ships lie, generally called the pool, extends almost 4 miles, nearly to Deptford, in which space more than 1000 vessels have been seen moored at one time! the rapidly increasing trade of this grand emporium of commerce, the regulations which have of late been made, for mooring the ships at more convenient distances, for a passage up and down the river, and the contiguity of the *West India* and *East India* docks to Blackwall are expected ere long, to extend the tiers of ships as far as that place. It was stated, in the year 1800, that the trade of the port of London had increased in the last, or 18th century, by 6547 vessels and 1,327,763 tons annually; and that (including repeated voyages,) 13,144 ships and vessels were then employed in this trade, to foreign countries, the colonies, and coastwise, besides 2288 lighters, barges, and punts, employed in the middle part of the *Thames*, and on the *Lea* river, and 3336 of the like kinds of vessels used below bridge, in the lading and discharging of vessels, together with 83 boats, sloops, cutters, and hoys, 3000 watermen's wherries, 155 bum-boats, and 194 peter-boats, the total number, (exclusive of ships of war, transports, and navy and victualling and ordnance hoys,) being 22,500 vessels of various sizes and dimensions, either trading to, or stationed within the pool or port of London; the total value of the goods imported and exported annually by them exceeding 67,000,000*l*. The corporation of the city of London, as conservators of the river *Thames*, and under the special authority of the above acts, are, at this time, carrying on considerable works for the improvement of this river: several mooring chains in the pool have been purchased of lord Guydir and others, and a harbour-master, approved by the Trinity-house, is appointed to regulate the mooring and conduct of vessels, agreeable to the 19, 29, and 39 of Geo. III.: one of the largest canals ever attempted has been cut, near $1\frac{1}{2}$ mile in length, 142 feet wide at top, and 24 feet deep! across the *Isle of Dogs*, for shortening the passage of vessels to and from the pool, and to avoid the long circuit by Greenwich and Deptford; Mr. William Jessop is the engineer, under whom the locks and other works of this canal were successfully conducted and nearly finished, when an unforeseen accident, by the blowing up of the coffer and preventer dams, just as the entrance locks were completed, on the 24th of July last, (1805) prevented this canal from being opened until the 9th of December, when the *Duchess of York*, West Indiaman, of 500 tons burthen, passed through the same, in presence of the lord mayor and corporation of

London. Several large sums of public money have been granted by the above acts out of the consolidated fund; for the repayment of which vessels passing through this canal of 200 tons or upwards are to pay 2*d*. per ton; those from 200 to 100 tons, 1*d*. per ton; from 100 to 50 tons, 1*d*. per ton; 50 to 20 tons, 5*s*. each, and boats and craft 1*s*. each. Two or more piers are intended to be built at the entrance, for facilitating the entrance of vessels to this canal. Between this canal and the entrance of the *East India* docks, there is a large mass of silicious pudding-stone, consisting of chert pebbles imbedded in a very hard cement, which lies in the bed of the river, and has proved fatal to several ships, on which account the committee, in September 1802, and on several other occasions, advertised for persons who would undertake to lower this rock 18 feet, its length being about 40, and breadth 30 feet; the newspaper accounts of the *Boddington* West Indiaman having struck on this rock on the 12th of September last appear to be incorrect, the rock being now surrounded by piles and booms, so that no ship can approach it. In the year 1773, Mr. James Sharp suggested the propriety of floating, or wet-docks, for the loading and unloading of ships in the *Isle of Dogs*; after much discussion a plan was adopted for this purpose, in the year 1799, called the *West India Docks*, and Mr. William Jessop and Mr. Ralph Walker were employed as engineers. On the 12th of July 1800, the first stone of this great undertaking was laid with much ceremony. On the 22d July 1802, an unfortunate accident occurred by the bursting of the coffer-dam at the entrance at Blackwall, but which did not prevent the great or import dock, from being opened for the use of West-India ships on the 3d of September 1802. This fine dock, the largest in Britain, is 2600 feet long, 510 feet wide, covering more than 30 acres of ground; its depth being 29 feet, and it is walled in the most substantial manner with bricks, and coped with immense blocks of stone. Three stacks of the superb warehouses on the banks of this dock were completed at this time: on the 22d of August 1803, several other warehouses on the N. side of the dock were finished, and declared ready for public use; and, on 5th July last, two warehouses on the south side, and the whole of that quay were completed. The outward-bound dock, 2600 feet long, 400 feet wide, and 29 feet deep, has been rapidly proceeding since the completion of the great dock, and is now almost ready, we believe, for opening. At Blackwall, and at Limehouse-hole, there are spacious entrance basons, connecting by tide-locks with the *Thames* river; from these entrance basons there are locks into the outward and inward, or export and import docks: these docks are calculated for the accommodation of 300 ships, 12 of which can conveniently enter or go out in one tide: there are to be six immense ranges of warehouses in the whole, with cellars, cranes, and every possible convenience: the whole is to be surrounded with a wall 30 feet high, and a wet fols 12 feet broad, and 6 deep: for security from fire, no dwelling-houses or work-shops are to be built within or near to the boundary wall; no gunpowder is to be suffered to enter the walls, or any fire, candles, or lamps to be lighted within the same, except the necessary street-lamps on the quays. The company were at first authorized to raise 600,000*l*. the amount of shares being 500*l*. each, which, in 1802, bore a premium of 28*l*. per cent.: the profits to the subscribers are limited to 10 per cent.: several loans of the public money from the consolidated fund have been made towards completing this design. Mooring-chains are provided in the river opposite the entrance basons, for the use of ships entering these docks, in which all West India goods whatever (except tobacco in some cases,) are to

be landed, and all outward-bound ships for the West-Indies are to load herein, or in the *Thames* at Blackwall; but the tonnage for the building and maintenance of these docks is, (by 39 Geo. III.) not levied exclusively on the West India trade, as every vessel both on its inward and outward voyage (except coasting vessels under 45 tons, king's ships, corn, fishing, and passenger vessels, and craft navigating above Gravesend,) is to pay: coasting vessels at the rate of 1d. per register ton; and ships trading to parts beyond the seas are to pay higher rates, amounting, in some cases, to 3½d. per ton; see the particulars, as also the rates for wharfrage, warehouse-room, cooperage, &c. in the *Agricultural Magazine*, vol. i. p. 115. Mr. Robert Edington, in his *Essay on the Coal Trade*, 1803, after estimating 4284 coal-ships to enter the port of London annually from the neighbourhood of Newcastle-upon-Tyne, with 1071 chaldrons each, on the average, (a quantity considerably short of the actual importation, see *Monthly Magazine*, vol. xvii. p. 99, and vol. xix. p. 99.) objects strongly to the above rate, which annually taxes the coals consumed in London and its vicinity with 4284l., on account of these docks, which they are not allowed to enter. For the general accommodation of ships unloading and loading in the port of London, another set of docks was, after much discussion, undertaken, in the year following, called the *London Docks*, (or sometimes the *Wapping Docks*.) Acts 40, 44, and 45 of Geo. III. Mr. John Rennie and Mr. Alexander were the engineers employed; on the 26th of June 1802, the first stone of these works was laid, by Mr. Addington, the then minister; and the same proceeded without any disaster or impediment, until the great dock, the entrance basin, and several of the warehouses were completed, and opened for use on the 1st of February last (1805). The great dock is about 1260 feet long, and 830 feet wide, and covers about 24 acres of surface: it is 29 feet deep from the top of the walls; but the depth of water is only 23 feet; the walls are of brick, coped with stone, and every part of the work is executed in the most complete and masterly style. On the northern side of the dock there is an open shed the whole length, for examining and weighing and the landing of goods, under cover from the weather, from whence a number of small trucks moving on rail-ways convey them to five immense stacks of warehouses behind them, or the cranes hoist them into carts, as may be wanted. Near the S. E. corner of this dock are two immense warehouses let to government for the stowage of tobacco; one of them is 762 feet long, and 160 wide, the other 250 feet long, and 200 feet wide, each being in one single room, without any partitions, and their roofs are said to exceed 6 acres of slating; they are but one story high, but have spacious arched vaults under them of the same extent, for the stowage of wine, oil, spirits, &c. Other large ranges of warehouses are to be built, and their fronts have been begun north of the present range of warehouses; the windows and doors of these last being bricked up, serve as a temporary wall to enclose the premises: warehouses are also intended on the west and south side, where the high temporary fence-wall at present stands. The only entrance at present to this dock, from the *Thames*, is near to Bell-dock in Wapping, where two massive piers of stone project into the river, and have a tide-lock between them, and further north is a curious iron double swing-bridge, in the line of Wapping-street, which we have already described; within this is the entrance basin, of an irregular figure, of about 3 acres extent: this basin is connected with the river at every high-water, by the opening of the gates, which shut again and retain the water at that height; from this basin ships lock up into the great dock, whose surface is kept about

3 feet above the height of ordinary tides, by a powerful steam-engine erected on the east side of the entrance basin for that purpose, and the bottom of the dock is about 15 inches above low-water mark in the river. There is designed to be another entrance from the *Thames* by means of Hermitage-dock, into the great dock at its S.W. corner; and from near the opposite or N.E. corner, provision has been made, and the connecting canal formed, which is to join it with another large dock, intended to be dug, and connect with the *Thames* at Shadwell. Notices were given in September last of an application to parliament for further powers, to proceed with the above works. The present dock is capable of accommodating 200 merchant ships, and the entrance basin will hold a vast number of small craft, without impeding the passage of ships to or from the great dock. The whole of the docks or warehouses are, when completed, to be surrounded by a very high wall to prevent depredations or the communication of fire, against the happening of which the same regulations are adopted as at the West-India dock above mentioned. Six large mooring chains are fixed at proper distances from each other in the great dock for ships to moor to, consisting of very large floating blocks of deal timber. This company were authorised by their first act to raise 1,500,000l., the amount of each share being 500l. They were required to purchase the concern of the Shadwell water-works for 50,000l.; and ample provisions are made for compensating the owners of the river-quays, the proprietors of street-cart licences, &c.: and full accounts of the receipts and expenditure of this company, and of the West-India dock company, are to be presented annually to parliament. The tolls or rates payable to this company, by ships which enter their docks, are for British coasting vessels (including colliers) 1s. per ton; five other classes of ships are enumerated, which are to pay from 15d. to 30d. per ton; see *Agricultural Magazine*, vol. iii. p. 162. For the landing, loading, and housing, and for shipping of goods of every different kind, the same sums respectively are to be taken by this company, as were usually paid at the different quays of the port of London in the year 1798. The whole of the site of these docks was covered either with streets and houses, or with gardens, and which the company had to purchase for immense sums of money. For the particular accommodation of the large ships belonging to the East-India company, a third spacious set of docks has been designed, and in the 43 of Geo. III. an act passed for enabling the company to raise 200,000l. for the purpose of building the *East-India Docks*; and to purchase the dock belonging to Mr. Perry's mast-house at Blackwall, for their entrance basin. Mr. Ralph Walker is the engineer; and on the 4th of March last (1805) the first stone of this great undertaking was laid by captain Joseph Huddart, and the works are now proceeding with the utmost expedition: the largest, or import dock, is to cover 18 acres of ground, the export dock is to be 9 acres in content, and the entrance basin about 3 acres: the depth of these docks is to be greater than either the *London* or the *West-India* docks; the entrance locks now building are 48 feet wide in the clear, and each gate is to be 27 feet wide. Near to Deptford, *Greenland-Dock* has its entrance, by a tide-lock, into the river *Thames*; this dock is about 900 feet long and 400 feet wide, and was constructed several years ago, for the accommodation of ships employed in the Greenland, or whale fishery, with suitable conveniences at proper distances for melting and refining their oil. It is intended that the *Grand Surry* canal shall have a cut into, and a passage for its barges, through this dock: and the same company are now excavating a dock near the termination of their canal, at Wilkinson's gun-wharf, Rotherhithe,

which seems to be intended to admit small ships from the *Thames*. At Deptford, Woolwich, and at Sheerness there are spacious dock-yards and naval arsenals on the banks of this river, and others at Chatham, within a few miles of it, on the *Medway* river. In the year 1800 it was proposed to make a large dock and yard, for repairing second and third rate ships of war, of which *Major General Bantam* has the direction, near the salt pans on the *Isle of Grain*, on the *Medway* side of it: its principal object is for repairing the ships stationed in the Downs and North Seas. In the year 1804 it was proposed to form a wet-dock, of about 12 acres extent, connecting with the *Thames* river, by *Northfleet* creek near Gravesend: the site of the old chalk pits is intended to be excavated for this dock, in which the new ships of war built at Deptford, Woolwich, and Chatham are to be received to be rigged and fitted for sea, instead of sending them to Sheerness; that the arsenal there may be wholly appropriated to the victualling and ordnance department. A pier is now building for the protection of *Sheerness* harbour, under the authorities of the acts of 41 and 42 Geo. III. At Margate, there was an ancient wooden pier in this river, for the protection of the hoys and vessels trading to that place, but in 27 Geo. III. an act passed for an excellent stone pier, which has since been there erected. The great distance which the inhabitants of Gravesend, and Grays-Thurrock, and all those parts, have to travel (over London bridge) to communicate with each other by land, gave rise, in May 1768, to the proposition by Mr. *Ralph Dodd* for a tunnel, or road arch, under the *Thames*, from near Gravesend to Tilbury Fort (see *Nicholson's Journal*, 4to. vol. ii. p. 473); and an act of 49 Geo. III. passed to authorise the raising of 50,000*l.*, in 100*l.* shares, for the *Thames Tunnel*, and to levy 2*s.* 6*d.* on each coach, 4*s.* on each waggon, 2*s.* on each cart, 1*s.* on each horse, 2*d.* on each foot-passenger, and some other tolls, for passing through this tunnel. Government to pay 100*l.* annually, in lieu of all tolls, for the passage of troops and of government stores of every kind: 80*l.* to be paid annually to his majesty, and 30*l.* to the corporation of Gravesend and Milton, in lieu of the right of ferries, near the intended tunnel, to which they are entitled. Mr. *Dodd* proposed his arch to be a cylinder of 16 feet diameter in the clear, and estimated that the same might be executed for 16,000*l.*, the length of the tunnel being 900 yards; but it does not appear that at this time, or for more than two years after, any borings had been made, even on the shore of the river where the tunnel was intended, to prove whether the chalk rock, which Mr. *D.* had calculated upon tunnelling in, existed or not: at length, about September 1800, a bed of chalk, supposed to be the same which appears on the surface at Gravesend, was discovered, by Mr. *D.*'s borings, at 72 feet beneath the surface, at Tilbury Fort; a steam-engine was thereupon erected, and a perpendicular shaft of 146 feet deep was sunk at Gravesend, all in chalk; when, by one of those unaccountable accidents to which abortive schemes seem peculiarly liable, this engine-house took fire, and was burnt down, and shortly after the scheme was given up altogether. In the last session of parliament (45 Geo. III.) an act passed for making other archways under the *Thames*, for the passage of carriages and foot passengers, between Rotherhithe and Limehouse; and we have since read that Mr. *Robert Vazie* is the engineer to these *Rotherhithe archways*, that the foot-way arch is to be made a little to the west of the *London-Dock* entrance, and the carriage-way arch at the ancient horse-ferry between Limehouse and Rotherhithe. On inquiry, we have been told, that the present scheme is, to sink a shaft on one shore of the *Thames*, with an engine thereon and pumps, and to continue the same to a sufficient depth, at

which to begin the tunnel in opposite directions, rising to the opposite shore of the river one way, and to a point sufficiently inland the other way, for a regular and proper ascent for carriages. We can hardly suppose that this matter has proceeded thus far, without its being ascertained, by a series of borings, quite across the river, at short distances from each other, that there is no fissure or crack in the clay, beneath the alluvial matters, which may be filled up with quicksand or other loose soil impracticable to tunnel through, under the bed of a river: but, if we admit the whole matter to be solid clay under the water-way or bed of the river, yet the number of houses which must be pulled down, or endangered, opposite to the tunnel, in this way of conducting the business, in order to bring the archway to the surface on one side of the river, and the inconvenient distance which that entrance will be from the water-side, are almost insuperable objections to its adoption. We have no doubt of the practicability of forming as many arch-ways under the *Thames* as may be wanted (if money is not spared, and scientific and proper men are employed on the work), but are of opinion that for such to succeed, the river must be piled off, for short lengths at a time, while the necessary excavation is made in the bottom for turning a length of the arch, and securely covering it with clay or puddle: and after several successive lengths are thus formed, the water and traffic of the river may be admitted over the part which is completed. Very powerful pumping-engines will be necessary, in this or any other way of conducting such a work with the probability of success. The *Thames* river, below London, is embanked through a great part of its course; the time when these banks were first erected is uncertain, but they appear to be of great antiquity; and during several hours of each tide, the adjoining meadows are 10 feet or more below the level of the water. At Dagenham, about 7 miles below Blackwall, a large breach in one of these banks happened, which captain *John Perry* succeeded in stopping, after several others had failed in their attempts. On the 5th of August 1776 the plan was first adopted of employing convicts in ballasting, and other works for the improvement of the river *Thames*, under Mr. *Duncan Campbell*; these men, properly ironed, are lodged in hulks, or old vessels, off Woolwich, and have principally been employed in enlarging the wharfs at Woolwich Warren, or Royal Arsenal, which work is still proceeding. In the year 1783, and again in 1802, the *London Lynn and Norwich* (or North London) canal was proposed to join the *Thames* river at Limehouse. In 1798 a new channel was proposed to be cut for the *Thames* river straight across the *Isle of Dogs*, and dams with sluices and locks to be made on the old course of the river, for converting the same, round the island by Deptford and Greenwich, into one vast floating dock for ships! About the same time, the *London Docks* were in contemplation, and a canal was proposed to extend from them to the *Thames* river at Blackwall; the *Isle of Dogs* canal has since been made, and in part answered both these purposes. In 1801 the *Canterbury and St. Nicholas-Bay* canal was proposed to join the *Thames* at the latter place; and in the same year the *London and Walham-Abbey* canal was intended to join at Bell-wharf in Shadwell. The *Thames and Medway* proprietors pay 1*s.* annually as an acknowledgment to the city of London, as conservators of the *Thames* river, for the liberty of connecting therewith.

THAMES RIVER (middle part). Acts 14 and 17 Geo. III. —The general direction of this part of the *Thames* river is nearly west, by a very crooked course of 37 miles between the counties of Surrey and Middlesex; the tide flows through the first 16½ miles thereof to Richmond bridge: its objects are the supply of London, and the immense trade which is carried

on with the rivers and canals westward: at Vauxhall creek it is joined by the *Grand Surry* canal; at Wandsworth entrance-basin, the *Surry Iron Rail-way* joins; at Brentford Creek the *Grand Junction* canal joins, and at Ham Haw, near Shepperton, the *Wey* river joins (2 miles from the junction with the *Basingstoke* canal). London, the first British town, has 864,845 persons; Wandsworth, Brentford, Kingston, Chertsey, and Staines are also considerable towns on this part of the *Thames* navigation; which commences in the *Thames* lower part at London bridge, and terminates in the *Thames* and *Isis* navigation at London stone, at the extremity of Middlesex county, about $\frac{1}{2}$ a mile above Staines bridge; from near Chelsea, Pimlico creek extends for about $\frac{3}{4}$ of a mile to Chelsea water-works engine. From low-water at Richmond bridge to London stone, 20 $\frac{1}{2}$ miles, is a rise of 36 feet; see a section thereof in *Gentleman's Mag. March*, 1771, and in *Zachary Allnutt's Considerations on the Thames River*, 1805, wherein it appears, that the navigation hereon is in two or three places interrupted by shallows, not exceeding 2 feet 9 inches depth of water in ordinary times. At Laleham, Mr. *John Rennis* gauged the stream of this river, in the dry season of 1794, and found 1155 cubic feet of water per second to be then passing down. The corporation of the city of London, as conservators of the river *Thames*, and by the 17 of Geo. III. above, were unauthorised to make any new side-cut by this part of the river, or to erect any weir quite across the channel of the river; and their exertions for the improvement of this navigation, so much in need of amendment, have been confined to the erecting of jetties and weir-hedges, for contracting the breadth of the stream in many of the shallow places, to the dredging or ballasting of others, to deepen the channel, and to the establishing of regular flushes of water, twice a week, or oftener, from the pounds and mill-dams in the upper part of the river, for enabling barges, during the run of such flushes, to pass the shallow places; except, that they have completed a good horse towing-path through the whole length of this navigation, beginning at Putney bridge, on the south shore of the river: immense sums of money (upwards of 1400l. per annum) having been expended on the above inefficient measures, and yet the navigation in all dry seasons continues intolerably bad, and also frequently interrupted and rendered dangerous by floods. We are happy to observe, that notices were given in September last (1805) for an act to authorise the making of weirs across the river, and side-cuts and locks, in the parishes of Laleham, Littleton, Shepperton, Sunbury, Chertsey, and Thorpe. The above act (17 Geo. III.) authorised the city of London to purchase certain local tolls on the navigation between Staines and Richmond, and to levy 4d. per ton per voyage up and down, for the above purposes; they have a commodious barge stationed on the river for the residence of a collector of this toll, and an annual account of all the receipts and disbursements under this act is presented to parliament. The *Grand Surry* canal was (by its act 41 Geo. III.) required to pay 2 guineas as a fine, and a rent of 60l. annually, for the liberty of connecting with this navigation; and the *Croydon* canal 40l. per annum; the *Surry Iron Rail-way* is to pay 10l. per annum; and the *Grand Junction* company are to pay 600l. per annum, and a toll of 1d. per ton on all goods which pass into or out of this canal. Among the bridges upon this navigation, *London Bridge*, at its commencement, built of stone in 1209, comes first to be noticed: the river at this place is about 900 feet wide, the bridge, which is 60 feet high and 74 feet wide, consists of 19 arches, the middle one of which is 72 feet wide, but the next thereon on each side are narrow ones, and no regular order is to be observed in the arrangement of the arches, which are

most of them of different widths, under 20 feet; the piers between them are immensely thick, being also surrounded with starlings or vast frames of piling and cross beams of timber, intended for the protection of the foundations of the bridge: previous to the making of the large lock or centre arch, in 1756 (by the removing of a pier and its starling, and turning one large arch instead of two) the clear water-way between all the starlings amounted but to 194 feet, and above the starlings (which are covered when the tide has risen about two thirds of its usual height) the water-way amounted to only 450 feet, or half the width of the river: a further obstruction also arises from the water-wheels, which are fixed on the upper side of the bridge at both of its ends, opposite to several of the arches, for pumping up water for the supply of the city of London and Borough of Southwark. By these contractions of the water-way, a fall and current is occasioned under this bridge, which for several hours of each tide is quite tremendous, and proves a most serious obstacle to navigation, as well of danger to the bridge itself. If Mr. *John Smeaton's* advice had not been quickly followed, in 1756, in returning and throwing in the stones, which had been recently taken up from the old middle pier, together with many cargoes of other large and rough stones, the adjoining starlings and piers of the great lock would certainly have been undermined, and the bridge have fallen: great quantities of chalk and Kentish rag-stones are now annually brought and deposited within the piling of the starlings, and between them, at the time they are repaired; a work for ever requiring to be done, in some part or other, of these clumsy obstructions to the waters and to navigation: immensely deep gulphs are formed at each side of the bridge by the pitch or fall of the water, and the soil and rubbish excavated therefrom is continually thrown up at a distance, so as to form large banks dry at low-water, in spite of a continual dredging or ballast-heaving, which is resorted to for removing them. These inconveniences, which had been long and loudly complained of, occasioned, about the year 1799, a proposal, for pulling down this bridge, and substituting two stone bridges, with capacious arches: these were to be placed near to each other and to connect at their ends; the centre arch of each was to have a draw-bridge, for admitting ships up the river, as far as *Blackfriars* bridge; the intention of the two bridges being, that one of the draw-bridges might always be shut down for the passage of carriages and persons, while ships might be passing through the other into or out of the basin between the bridges. Another proposal was, to construct a cast-iron bridge of one single arch of 600 feet span and with 65 feet clear opening above high water; as we have already mentioned: these, and other projects for the same purpose were minutely and carefully examined by a select committee of the house of commons, and their reports, together with views of the different proposed bridges, have been since published, and a proposal made for a cast-iron bridge of three arches, resting on stone piers, the centre arch 65 feet high for the passage of ships; in September 1802, the city of London gave notices of their intention to apply for an act of parliament for removing *London bridge* and building another, but nothing further, we believe, has since been done. *Blackfriars Bridge* is an elegant stone structure, offering scarcely the least impediment to the navigation; it was built in 1770, by Mr. *Robert Milne*; the river in this place is 995 feet wide, it has 9 large elliptical arches, the centre one 100 feet wide, the others regularly diminishing to the outside ones which are 70 feet each. The whole cost of this bridge, in the 10 $\frac{1}{2}$ years during which it was in hand, was 150,840l. *Westminster Bridge* was built of stone in the year 1750; the river in this

place is 1220 feet wide; there are 17 large, and two small semi-circular arches in this bridge, the centre one 76 feet wide, the others diminishing by 4 feet each in width, to the small ones at the sides; the cost of this bridge and its avenues was 389,500*l.*, and it was about 10 years in hand. At Battersea and at Putney there are narrow, low, and inconvenient wooden bridges over this fine river. On the 4th of June 1783, a handsome and convenient stone bridge was begun over this river at Kew, and in the year 1774, another stone bridge was begun at Richmond. About the year 1801, a new stone bridge was built over this river at Staines, but it was shortly after obliged to be taken down, owing to a settlement therein; an iron bridge was next substituted, and opened on the 3d of September, 1803, of one arch, with 180 feet span, rising only 16 feet above the stone abutments on which it rested; but this, we are sorry to add, has lately suffered the fate of the other, and has necessarily been taken down, a circumstance the more to be regretted, as this was the first cast-iron bridge brought into use in this part of the kingdom. At Walton, there is a curious bridge, consisting of a large wooden opening, and smaller brick arches on each side of it. It may be proper to add, that the intention has very recently been announced, of building a new stone bridge over this river from Vauxhall to Millbank, with a new road over the same from Vauxhall turnpike across Totterdell fields to Pimlico. In the year 1770, and again in 1794, the *Maidenhead and Isleworth* canal was proposed to join this river at Isleworth and at Bolter's Lock, or Taplow mill; in 1792, the *Hampton Gay and Isleworth* was proposed to join at the latter place; in 1801, the *Leatherhead and Thames* railway was proposed to join this river at West Moulsey, and an extension of the Grand Surrey canal was intended to Kingston; in 1802, a cut from the proposed western branch of the *Grand Junction* canal was proposed to join at Ham Haw opposite to the *Wey* river; and, in 1803, the *Portsmouth and London* railway was proposed, to terminate in Stamford street, near Blackfriars bridge.

THAMES AND ISIS NAVIGATION. Act 11, 15, 28, and 35 of Geo. III.—The general direction of this navigation is nearly N. W. by a very serpentine and crooked course of about 110 miles between the counties of Surrey and Berks, and of Bucks, Oxford, and Gloucester: its western end is considerably elevated; its objects are the supply of London and the carriage of coals, and a variety of other articles: near Reading it connects with the *Kennet* river; at Abingdon, the *Wilts and Berks* canal joins this navigation: at Badcock's garden in Oxford, this navigation is joined by the *Oxford* canal, and at Godstow, by the *duke of Marlborough's* cut from the same canal. Oxford is the 38th British town, with a population of 11,694 persons, and Reading is the 55th, with 9,742 persons; Staines, Windsor, Maidenhead, Great-Marlow, Henley, Wallingford, Abingdon, and Lechlade, are also considerable towns on this navigation, which commences in the *Thames* middle part at London-Stone near Staines, and terminates in the *Thames and Severn* canal at Lechlade. From Staines-stone to the water above Bolter's Lock, 15½ miles, is a rise of 34 feet: thence to the entrance of the *Kennet* river 24½ miles, has a rise of 27½ feet, besides the rise at the weirs; thence to the termination to the *Thames* and beginning of the *Isis* river, is about 23 miles; thence to the *Wilts and Berks* canal about 10 miles; thence to the *Oxford* canal about 8 miles, and thence to Cricklade about 29 miles. The Gentlemen of the counties adjoining this navigation are Commissioners for executing, in different districts, the above acts; they have borrowed 60,800*l.* and have expended the

same, over and above the surplus of the tolls, in making 24 side-cuts with opening weirs and pound-locks, with a horse-towing-path, and other works for improving this navigation, which is now accomplished, so that very long and wide barges drawing 3 feet 10 inches, can in general pass the same; the rate of tonnage is only ½ per ton per mile; and an account of the receipts and expenditure on this concern is annually presented to parliament. In 1796, the receipts amounted to 9,830*l.* in 1801, to 10,060*l.* in 1802, to 7,173*l.* Mr. Zachary Allnutt is engineer to the 2d and 3d district of this navigation. In the year 1800, Mr. Wilson prepared a design and model for his Majesty, of a cast-iron bridge, of one arch, proposed to be erected over the *Thames* at Datchet. In the year 1770, the *Reading and Maidenhead* canal was proposed to join this navigation at Sunning, and at Bolter's lock; in 1802, a western branch of the *Grand Junction* canal was proposed to join this navigation at Harleyford near Great Marlow, and crossing the same at that place, it was to proceed to join it again near Reading; and in the same year another branch from the *Grand Junction*, through Aylesbury, was proposed to join this navigation near to Abingdon, and to the *Wilts and Berks* canal.

Thames and Avon Canal. In the reign of Charles II., Mr. Joseph Moxon was employed to survey the line for a canal, and a bill was prepared and brought into parliament, from the *Thames and Isis* navigation at Lechlade, by Cricklade, Malmesbury, Chippenham, and thence by the course of the *Avon* river to Bath, 40 miles in length: in 1754, this design was again revived, with the idea of employing the soldiers upon it; and it was stated that a canal 50 feet wide at top, 30 at bottom, and 4 feet deep, might thus be completed for 1000*l.* per mile.

THAMES AND MEDWAY CANAL. Act 40 and 44 of Geo. III.—The general direction of this canal is S.E. for 8½ miles in the county of Kent; it is level with the ordinary high tides in the river *Thames*: its object is for shortening the voyage of barges from Gravesend to Chatham round by the Nore; Chatham is the 46th British town, with a population of 10,505 persons, and Rochester the 90th, with 6,817 persons; Gravesend is also a considerable town near this canal, which commences in the *Thames* river at Gravesend, and terminates in the *Medway* river at Nicholson's ship-yard in Friendsbury, with a cut from Whitewall on the line of this canal to the *Medway* at Strood, opposite to Chatham royal dock-yard. Tide-locks and entrance basins are to be made at each of the three terminations of this canal; Mr. Ralph Dodd was the projector of this canal, on which Mr. John Rennie and Mr. Ralph Walker have since been employed. In December 1801, this canal was completed from Gravesend to Denton. The company were authorised to raise by the first act 60,000*l.* in 100*l.* shares, and a further sum by the last act, and they are to pay 1*s.* annually to the city of London as conservators of the *Thames* river, for the liberty of connecting therewith, and 1*s.* to the corporation of Rochester, as conservators of the *Medway*, for the same privilege.

THAMES AND SEVERN CANAL. Act 23, 31, and 36 of Geo. III.—The general direction of this canal is East, for 50½ miles in the counties of Gloucester and Wilts: it crosses the Grand Ridge by a tunnel; its objects are a communication between the *Severn* and *Thames* rivers, the supply of the country through which it passes with coals, deals, &c. and the export of farming products. Stroud is the 114th British town, with a population of 5,422 persons; Minchinhampton, Cirencester, Cricklade, and Lechlade, are also considerable towns on or near to this canal; which com-

mences in the *Stroudwater* canal at Wallbridge near Stroud, and terminates in the *Thames and Isis* navigation at Lechlade: it has a branch of about 1 mile in length to the town of Cirencester. From the *Stroudwater* canal to Sapperton or Salperton, $7\frac{1}{2}$ miles, is a rise of 243 feet by 28 locks; thence, the summit pound continues through the Tunnel, $2\frac{1}{2}$ miles, to near Coates, and level; thence, to the *Thames and Isis* navigation, $20\frac{1}{2}$ miles, is a fall of 134 feet by 14 locks. The first 4 miles of this canal from Stroud to Brinscombe-port Basin, is of the same width and depth as the *Stroudwater* canal, and is navigated by the *Severn* boats; the remainder of the line is 42 feet wide at top, 30 at bottom, and 5 feet deep; at Brinscombe-port, goods going eastward are removed into barges 80 feet long and 12 wide, which carry 70 tons each. The famous tunnel on this canal at Sapperton, is 4300 yards long, the arch being 15 feet wide in the clear, and 250 feet beneath the highest point of the hill, which proved to be hard rock, much of which required blasting, and some of it was so solid as to need no arch of masonry to support it; the other parts are arched above, and have inverted arches in the bottom; the cost of excavating this tunnel, in 1788, amounted to 8 guineas per cubic yard. The summit level of this canal is supplied by a feeder brought through lord Bathurst's gardens. Mr. Robert Whitworth and Mr. Joseph Clowes, were the engineers. On the 20th of April, 1789, the Sapperton tunnel was finished, and on the 19th of November of the same year, the whole line was completed and opened. We are sorry to have heard it remarked, that this canal has been conducted through porous gravelly soils, when a line for the same, equally convenient, might have made the cutting fall in a clay soil, and that puddling has been in too many instances neglected or has failed, by which the canal is rendered short of water, and the land and mills have been greatly injured: fanciful round buildings like towers have been made in different places on this canal, for the residence of the lock-keepers. This company were authorized to raise 255,000*l.*, the shares being 100*l.* each; there was a provision that 3 per cent. interest should be paid (out of the principal) to the subscribers on their shares, until the canal was completed and opened; we have heard that the present profits are not much above 1 per cent. No stamps were necessary to the proceedings of this company. The rates of tonnage and the regulations thereof with the *Stroudwater* company, are very long. See *Phillips's 4to. History*, pages 222 to 225. Manures for the adjoining lands are to pass toll free: less than 6 tons not to pass the locks without paying for that weight; $\frac{1}{2}$ mile-stones to be erected. In 1799, this company offered bounties for introducing the coals brought by their canal to the western parts of Oxford and Berk shires. The *Gloucester and Berkeley* company are to compensate this company, in case the construction or repair of their works interrupts at any time the communication with the *Severn*. In September 1800, it was intended to make from near Ingleham a forked branch passing Faringdon and Highworth, to connect with the *Wilts and Berks* canal in two places.

THANET'S CANAL. Act 13 Geo. III.—The direction of this canal is nearly N.E. for about $\frac{1}{4}$ of a mile in length, in the West Riding of Yorkshire; it is considerably elevated, near to Skipton, which is a considerable town; it commences in the *Leeds and Liverpool* canal, near Skipton, and terminates at Skipton-castle, lime-stone quarries. It was cut at the private expence of the earl of Thanet, through whose estate alone it passes, except one close: its object is to convey coals to the lime-kilns, and to export lime as a manure and for building.

THYRN AND BURE NAVIGATION. The general direction of these rivers is about N.W. for nearly 30 miles in the county of Norfolk: they are not greatly elevated above the sea in any part: the objects are the import of coals, deals, &c. and the export of farming products. Yarmouth is the 27th British town, with a population of 14,845 persons; Aylsham is also a considerable town on this navigation, which commences in the *Ture* river Yarmouth, and terminates at the town of Aylsham: it has branches from near Thurne and Horning, through the fens and broads, to Hickling and Dillham, about 8 and 10 miles in length.

TIVEY RIVER. This river, (sometimes called the Tivey or Teifi river,) has nearly an east course for about 39 miles, between the counties of Cardigan and Pembroke, and Caermarthen in South Wales: its eastern end is considerably elevated: its objects are the supply of Llanbedr and Cardigan, and the export of agricultural products. Cardigan, Kilgerran, Newcastle-in-Emlyn, and Llanbedr, are considerable town on this river, which commences in the tide-way in St. George's channel, and terminates at Llanbedr, or Lampeter.

TONE AND PARRET NAVIGATION. Acts 10 and 11 William III. 6 Anne, and 44 Geo. III.—The general direction of this navigation is nearly south, by a bending course of about 27 miles in the county of Somerset: its southern end is considerably elevated: its objects are the import of coals, and the export of agricultural products; at Borough chapel it is joined by the *Parret* river. Taunton is the 106th British town, with a population of 5794 persons. Bridgewater is also a considerable town on this navigation, which commences in the tide-way in Bridgewater-bay, at Start point, in the Bristol channel, and terminates in the *Grand Western* canal at the town of Taunton. In September 1798, a cast-iron bridge was completed, consisting of one arch of 75 feet span over the *Parret* river at Bridgewater, at the expence of 4000*l.* (See our article BRIDGE). It was erected in the place of a stone bridge, said to have been built about the year 1300. In 1796, the *Bristol and Taunton* canal was proposed to connect with this navigation at Bridgewater.

Topeliff and Pierce-Bridge. In June 1801, it was proposed to form a canal from the *Sawle* river at Topeliff to Pierce-bridge on the *Tees* river: the intention of this canal was for supplying the north riding of Yorkshire with Durham coals.

TORRIDGE RIVER. The direction of this river is south for three miles, near to the north-west coast of Devonshire: the tide flows through its whole length: it commences in the *Taw* river near Appledore, and terminates at Biddeford bridge: its object are the supply of Biddeford, a considerable town, with coals, &c. and the export of agricultural products. The spring tides rise 18 feet at Biddeford.

TOVEY RIVER. The direction of this river, (sometimes called the Towey), is north, for about $8\frac{1}{2}$ miles, in Caermarthenshire in South Wales: the tide flows through its whole length: its object is the supply of Caermarthen, which is the 113th British town, with a population of 5,548 persons: it commences in the Bristol channel, at St. Ithmael's, and terminates at Caermarthen bridge. In September 1804, it was intended to apply for an act to improve the port, quays, and dock at Caermarthen.

TRENT RIVER, (lower part). Act 34 Geo. III.—The general direction of this navigation is nearly S.S.W. by a bending and crooked course of about 116 miles, skirting Yorkshire for a short distance, and through the counties of Lincoln and Nottingham, and between those of Leicester and Derby: it is not greatly elevated in any part: its navi-

gation is of vast importance to the country, owing to the many communications which it forms with other rivers or canals: at Keadby it connects with the *Stainsforth and Keadby* canal; at Stockwith, with the *Idle* river, and near the same place with the *Chesterfield* canal; at Torksey, with the *Foss-dyke* canal; at Crankleys, in South-Muskham, with the *Dean* river; at Trent-bridge, near Holme-pierpoint, with the *Grantham* canal, and the *Nottingham* canal; near Sawley, with the *Loughborough* navigation, or *Soar* river, and the *Erewash* canal. Nottingham is the 17th British town, with a population of 28,861 persons; and Newark is the 91st, with 6,730 persons. Burton-upon-Strather, Gainborough, Newark, Southwell, and Bingham, are also considerable towns near this navigation; which commences in the *Humber* river at Trent-fall, (at the junction of *Ouse* river, and *Market-Weighton* canal,) and terminates in the Upper *Trent* river at Sawley-ferry, at the junction of *Derwent* river, and the *Trent and Mersey* canal. It has a side-cut of 10 miles in length, made in pursuance of the above act, for avoiding 21 shoals, and 2 bridges, which occur in 13 miles of the river between Trent bridge, at the commencement of the *Nottingham* canal, and Sawley ferry, at the commencement of the *Trent and Mersey* canal. This cut (sometimes called *Trent Canal*), has a rise of 28 feet, and it crosses and connects with the *Erewash* canal near Sawley; it has also a short cut and lock into the *Trent* in Beeston. The lower part of this river is through fens, and is embanked on both sides: it is subject to very great floods: the tide flows to Gainborough, so that small vessels can come up to that place; but between this and Wilden-ferry, a great number of shallows occur, owing, in a great measure, to the too great width of the river: Mr. John Smeaton, who examined it in 1761, states, that in several places in the common state of the river, in dry seasons, there was not above 8 inches depth of water; that at such times, without the aid of flushes from King's mills upon this river, and the lowest mills upon the *Derwent*, navigation was impracticable. The 33 of Geo. III. for *Grantham* canal required the proprietors of this navigation to deepen the bed of their river, so that there shall always be 30 inches deep of water in the driest seasons for boats to pass between the *Grantham* and the *Nottingham* canals, and by which they may also now pass into the *Trent Canal*, for avoiding the shallows above Nottingham. An act was passed a few years ago for building a new bridge over this river at Gainborough. In 1801 a new stone bridge was intended at Gunthorpe-ford. In the year 1789 and 1790, several acres of land were gained from the wide muddy banks of this river, simply by staking down rows of furzen faggots thereon, to check the current, and encourage the abundant deposit which this river makes, wherever its waters become stationary; (see *Agricultural Magazine*, vol. vii. p. 93.) a circumstance which proves of immense advantage in many instances, by the warping of land near this river in floody times, to improve it. The flood which happened in the beginning of 1800, forced a new and much straighter course for this river below Gainborough, and occasioned the old crooked channel to be deserted. For making the new side-cut, or *Trent canal*, this company were authorized to raise 23,000l. in 50l. shares: and they are allowed to collect a variety of tolls on different parts of this cut and the river. See *Phillips's 4to. History, App.* pages 169 and 170. But these were not to take place until 13,000l. had been expended under the above act, which embraces the improvement of the river, so that there may be always 30 inches deep of water, the making of horse towing-paths, purchasing the Nottingham hauling-machine, or capstern, &c. The profits of the *Trent canal* are not to exceed 7 per cent. By

the 33 Geo. III. for *Derby canal*, only half the usual rates are to be charged on goods passing only three miles on this river, in their way to or from that canal: and by 33 Geo. III. for *Grantham canal*, this company are to receive 14d. per ton for lime, and 3d. per ton for all other goods (except road-materials and manures), which cross this river, when deepened as above, between the *Grantham* and *Nottingham* canals. In 1760, the *Wilden and Kings-Bromley*, and in 1765, the *Ternbridge and Winsford* canals were proposed to join this river at Wilden-ferry, where the *Trent and Mersey* canal now joins.

TRENT RIVER, (upper part). Acts 10 and 11 William III.—The general direction of this navigation is nearly W.S.W. by a crooked course of about 19 miles, in Derbyshire and Staffordshire, and skirting Leicestershire: it is not very greatly elevated above the sea, in any part: its objects are the carriage of coals, and the export of salt, gypsum, earthen-ware, ale, and agricultural products: it connects at Swarkstone with the *Derby canal*, and has the *Trent and Mersey* canal running the whole length almost by its side, and communicating with it at its two extremities. Burton-upon-Trent is the only considerable town on this navigation; which commences in the lower *Trent* navigation at Wilden Ferry (at the commencement of the *Derwent* river and *Trent and Mersey* canal,) and terminates near Burton, at a branch from the *Trent and Mersey* canal. The earl of *Uxbridge* is the sole proprietor of this navigation, and all other persons are restricted from erecting or using wharfs or warehouses on its banks without his special consent. The earl or his lessees are entitled to 3d. per ton, on goods navigated on any part of this navigation; which was said, in 1765, to be unimproved, except by the erection of locks at two different mill-weirs; and, more than 20 shallows then existed, over which boats could not pass in dry seasons, without flushes of water: strange stories were at that time related of the conduct of these lessees, and insinuations were made, that a barge loaded with stones was sunk by design in Kings-mill lock, and which lay there almost 9 years, and obliged all goods to be unloaded into fresh boats at that place! happily the rivalry of the canal by its side, renders such an occurrence hereafter unlikely ever to happen. The bridge over this river at Burton-upon-Trent is said to be the longest in England, being 154½ feet long, with 34 arches. It may be proper here to remark, that Mr. Smeaton, in 1768, recommended the making of a long bridge or water-road adjoining the lower part of this river, between Muskham and Newark, that should have 300 yards long of clear water-way through its 72 arches! In 1793, the *Bredon* rail-way was proposed to join this navigation at Weston Cliff; in 1796, the *Commercial* canal, and in 1797, an extension of the *Ashby-de-la-Zouch* canal was proposed to connect herewith at Burton.

TRENT AND MERSEY CANAL. Acts 6, 10, 15, 16, 23, 25, two of 37, and 42 Geo. III.—This canal (sometimes called the *Grand Trunk*, or the *Staffordshire canal*), has its general direction about E.S.E. by a very bending course of 93 miles in the counties of Chester, Stafford, and Derby: it crosses the grand-ridge by a tunnel: its objects are the export of coals, salt, pottery-ware, lime, gypsum, Swichland-slates, agricultural products, &c. and forming parts of the grand inland communications between Liverpool and Manchester, with Hull, Bristol, and London; at Quiton's-wood in Stoke, it connects with the *Newcastle-under-line* canal; at Great Haywood with the *Stafford and Worcester* canal; at Fradley Heath with the detached part of *Coventry* canal; and at Swarkstone it crosses and connects with the *Derby canal*. Although none of the towns on this long canal appear to have so many as 5000 inhabitants, yet

Northwich, Middlewich, Sandbach, Newcastle-under-line, Stone, Stafford, Rudgley, Litchfield, and Burton-upon-Trent, on or near to the same, are considerable places. The commencement of this canal is in *Bridgewater's* canal at Preston-brook, and its termination in the *Trent* lower navigation, at Wilden-ferry near Shardlow, the point of junction of the *Trent* canal, or side-cut, the upper *Trent* navigation, and the *Derwent* river: from Etruria, a principal branch (sometimes called the *Caldon Canal*), proceeds by Froghall to Uttoxeter, by a very bending course of about 28 miles in length; from this, at Froghall in Kingsley, there is a rail-way branch of $3\frac{1}{2}$ miles to Caldon-low lime works, also from Stanley Moss in Endon there is a canal branch of about $3\frac{1}{2}$ miles to the town of Leek, and from Shelton, a short cut to Cobridge: from Stoke-upon-Trent there is a rail-way branch to Lane-end; and from Etruria another to Handley-green; from Longport to Dale-hall there is a canal-branch, and the same is continued forwards by a rail-way to the potteries at Burslem; there is a cut 1 mile in length to the *Trent* river near Burton. Near Lane-delph, and in Harecastle there are short cuts or tunnels, extending to the pits or seams of coals. From *Bridgewater's* canal to Middlewich, 18 miles, is a level; thence to near Talk, 11 miles, is a rise of 326 feet by 35 locks; thence along the summit-pound, and through Harecastle tunnel to the Caldon branch at Etruria, 6 miles, is level; thence to the *Stafford and Worcester* canal at Great Haywood, 17 miles, is a fall of about 150 feet and 19 locks; thence to the *Coventry* canal at Fradley Heath, 13 miles, is about 32 feet, and 4 locks; thence to Horninglow wharf, 12 miles, is about 86 feet fall, and 11 locks; thence to the *Derby* canal at Swarkestone, 10 miles, is about 16 feet fall, and 2 locks, and thence to the *Trent* river at Wilden-ferry, 6 miles, is a fall of about 32 feet, and 4 locks. From the summit level of the line at Etruria to near Bagnal on the Caldon branch, $5\frac{1}{2}$ miles, is a rise of 75 feet, by 7 locks; thence to Stanley-Moss, 1 mile, is level; thence to Froghall, $9\frac{1}{2}$ miles, is a fall of 61 feet, by 9 locks. From Preston-brook to Middlewich, at the western end, and from Wilden-Ferry to Horninglow near Burton, at the eastern end, the width of the canal at top is 31 feet, at bottom 18, and it is $5\frac{1}{2}$ feet deep; the locks here are 14 feet wide, adapted to river barges of 40 tons burthen; the middle part of the canal, and its branches, are 29 feet broad at top, 16 feet at bottom, and it is $4\frac{1}{2}$ feet deep, the locks being only 7 feet wide; the boats are 80 feet long, 6 feet wide, and carry 18 to 20 tons of lading. There are 16 public wharfs on this canal with warehouses, cranes, weighing-engines, and other necessary conveniences at each. Over this canal there are 258 road and foot bridges, and under it 3 large aqueducts, and 124 lesser ones and culverts. Through Harecastle Hill is a tunnel of 2888 yards in length, and upwards of 70 yards below the hill; this tunnel intersects, and has cross branches to, several veins of coals in the hill, and is also famous for being the first public canal-tunnel constructed in England; the driving of this tunnel, in 1776, cost about 70s. 8d. per yard run: the height of the arch is 12 feet, and its width 9 feet within side. At Preston-on-the-hill near *Bridgewater's* canal is another tunnel of 1241 yards in length; at Barton in Great Budworth is another, 572 yards long; at Saltersford, or Saltersfield, in the same parish, is another of 350 yards long, and there is a fifth tunnel at Armitage, or Hermitage, of 130 yards in length; the heights of these last tunnels are $17\frac{1}{2}$, and their width $13\frac{1}{2}$ feet. At Monks-bridge there is an embankment 13 feet high of $1\frac{1}{4}$ mile in length, and an aqueduct bridge over the Dove river of 23 arches, from 15 to 12 feet wide each. At Alrewas is an aqueduct over the

Trent river, with 6 arches of 21 feet span; and near Middlewich is another aqueduct over the Dane, with 3 arches of 20 feet span. In the Rudyerd vale, N.W. of Leek, near the grand-ridge, is a reservoir of 160 acres extent, with an artificial head 30 feet in height; from this a feeder conducts its water to the Leek branch, and thence into the summit pounds of the Caldon branch, and of the main line: there are four smaller reservoirs near the summit, which measure together 60 acres; all waters within 5 miles of the line are allowed for the use of this canal. The rail-way branch to Mr. Gilbert's Caldon lime-works, made about the year 1777 or 1778, was composed of cast-iron bars pinned down upon rails of wood fixed across wooden sleepers, as we have before described; it appears to have been let out, before the true principles of this excellent mode of conveyance were so well understood as at present, being very crooked and with frequent variations in the angle of its ascent; in the last of the above acts, there is a provision made for varying the line of, and improving this rail-way. It is said to have cost, at first, about 1760l. per mile; in 1794, one horse, we are told, for 9 months in the year, made in each week three journeys on four of the days, and two journeys on the other two days, hauling 3 tons 6 cwt. of limestone down each journey, from the quarries at Caldon to Froghall wharf; for forwarding this stone to the canal at Etruria, the company found boats, the bargeman found his own horse and boy, towing lines, &c. and delivered the stone at 9d. per ton, the distance being about $16\frac{1}{2}$ miles. Mr. James Brindley, Mr. John Smeaton, and Mr. Hugh Henshall were the engineers employed or consulted on the works of this canal, which were begun in July 1766; in April, 1773, the line eastward of Harecastle tunnel was completed, and in May, 1777, the whole line was completed and opened: the Leek branch, the extension of the Caldon branch to Uttoxeter, and the Cobridge branch have been undertaken since the year 1797; the Lane-end, Handley-green, and Burslem branches were projected in 1802. The first act above included 6 miles of the west end of *Bridgewater's* canal, but with a power to assign or make over the same to the duke of Bridgewater, which was accordingly done; the 6th act above assigned 11 miles of the *Coventry* line, between Fradley-heath and Fazeley, to this company, who completed the same, and then sold it in equal moieties to the *Coventry* and the *Birmingham and Fazeley* companies, as before mentioned. This company have been authorized at different times to raise 334,250l. the amount of their shares was 200l. each, until 42 Geo. III., when a division of them was made into 100l. shares. The rates of tonnage are $1\frac{1}{2}$ d. per ton per mile, with reasonable wharfage after 24 hours, on all kinds of goods; but paving and road-materials (lime-stones excepted,) and manures pass toll-free on the pounds and through the locks, when water runs waste over their paddle-weirs. The act 33 Geo. III. for *Derby* Canal, granted some rates to this company on goods crossing this canal or passing out of it into the *Trent* by the *Derby* canal; see *Phillips's 4to. History, Appendix*, p. 58 and 59. In the years 1760 and 1765, the *Wilden and Kings-Bromley*, and the *Tern-bridge and Windsford* canals were proposed through parts of the tract now occupied by this canal: in 1793, the *Sandbach* canal was proposed to join near that place, and the *Bredon* rail-way was intended to be connected herewith near Welton-cliff: in 1796, the *Commercial* canal was proposed, to cross this canal at Horninglow near Burton, and again near Burslem; in 1797, an extension of the *Asby-de-la-Zouch* canal, to join this at Horninglow was proposed; the design of the two last proposals was, an extension of the wide canals for 40 ton boats, and with the same view a plan was, in 1797, mentioned of

widening this canal and its locks, bridges, &c. so that wide boats might pass between Fradley-Heath, and the east-end of Harcastle tunnel.

TWEED RIVER. This river seems to be navigable but about 1 mile from the sea to Berwick bridge, between Berwick liberty and a detached part of Durham county. Berwick is the 82d British town with a population of 7,187 persons; it has a great trade in salmon, which are caught in great quantities in this river, and 40,000 kits of it have been pickled and sent off from this town in one year; 75 to 80 vessels are employed in fishery, and the trade of this place connected therewith. At Berwick there is a stone bridge 947 feet long, with 15 arches over this river. At Kelso several miles higher up on this river, a stone bridge was, in 1798, washed away, and a cast-iron bridge was proposed to be erected in its stead.

TYNE RIVER. Acts 9 and 10 Henry V., 6 and 7 William III., and 41 Geo. III.—The general direction of this river is nearly W.S.W. by a crooked course of about 14 miles between Durham and Northumberland; the tide flows through its whole length; its great object is the export of coals. Newcastle-upon-Tyne is the 10th British town with a population of 36,953 persons, South Shields is the 65th with 8,108 persons, and North Shields the 80th with 7,280 persons; Gateshead is also a considerable town near this river, which commences in the North Sea at Tyne-mouth, and terminates at Blaydon in Winlaton. A very peculiar kind of vessels, as before mentioned, is in use upon this river for carrying coals from the waggon-roads, or railways, and staiths to the ships; these are called keels, and are limited (by 11 and 15 Geo. III.) to 25½ tons of lading, or 8 Newcastle chaldrons of coals. From an humane set of Gentlemen resident upon, and concerned in the trade of this river, originated the idea, and they offered a public reward for the *life-boat*, which Mr. *Greathead* brought to perfection, and first tried at the mouth of this river on the 30th of January 1790. (See the article *LIFE-BOAT*). The coals from the numerous coal-mines near this river were formerly delivered to the colliers or coal-ships lying below Newcastle bridge by means of the keels, but of late years several mines have been opened on both sides of the river, and the railways therefrom are conducted to staiths or spouts on the quays, by which means the coals are shot at once into the holds of the ships. Wooden rail-ways were, since about the year 1680, in use between the mines and this river, some of them of considerable length, those to Tanfield-Moor are 10 miles long. In April, 1798, an inclined-plane of 864 yards in length, was opened from Benwell, or Bywell collieries, as before mentioned: in October 1803, a rail-way from Mr. *Temple's* Jarrow mine (128 fathoms deep) was opened to the river. No less than 35 sorts of coals, or rather the produce of as many pits, are usually shipped from this river for London, amounting to 700,000 chaldrons annually: see *Edington's Essay*, &c. p. 31. On some of these mines, immensely large steam-engines are employed; in 1763, a new engine was erected at Walker colliery, with a cylinder 74 inches diameter and 10½ feet long, which weighed 6½ tons, and was calculated to lift 307 cwt. of water by each stroke of its pump. There is an ancient stone bridge of 9 arches over this river, which was greatly damaged by a flood in 1771; in the year 1801, it was suggested to remove as many of its piers as would form a 144 feet opening near the south bank, and to construct an iron arch over the same, high enough for the keels to pass without lowering their masts. The conservators of this river, in pursuance of the last of the above acts, have deepened and improved the same and its quays; in 1801, a new dry, or graving-dock, was opened at South

Shields, capable of receiving ships at neap tides; in 1802, an act passed for building a new light-house at Tyncmouth with reverberating lamps, instead of a coal fire blown by bellows, before used. In the year 1798, it was proposed to make a tunnel or road-arch under the *Tyne* river from North to South Shields for the passage of carriages and passengers, and the expence thereof was estimated at 6,993l. In 1795, the *Newcastle and Carlisle* canal was proposed to join this river near Newcastle; in 1796, the *Newcastle and Haydon bridge*, and in or before 1801, the *Newcastle and Maryport* were also proposed. In 1797, and again in 1802, the *Durham and Chester-le-Street* canal was proposed to join this river near Gateshead; and in 1803, the *Tyne and Beamish* canal was proposed through part of nearly the same tract.

Tyne and Beamish Canal. In 1803, it was proposed to make a canal from the *Tyne* river, near Gateshead, through Gateshead, Wickham, Lamesley, and Birtly townships, to Beamish iron works and coal-mines.

ULVERSTONE CANAL. Act 33 Geo. III.—The direction of this short, but large canal, is nearly N.W. for 1½ mile in Lancashire; it is level with high-water at ordinary tides, with a sea-lock at its entrance; its object is to admit ships to Ulverstone town. This canal commences at Hammer-side hill in Morecambe bay in the Irish Sea, and terminates at the new basin and wharfs at Ulverstone; the canal is 65 feet wide at top, 30 feet at bottom, and 15 feet deep; the lock is 112 feet long; at the lowest neap tides there is a depth of 9 feet water at the gates, and at spring tides of 20 feet; a public swing-bridge is built at Hammer-side. That able engineer, Mr. *John Rennie*, was employed on this canal, and completed it about July 1797. This company was authorised to raise 7,000l., the amount of their shares being 50l. each. Coals may be brought to this canal from the *Lancaster* canal, without paying the sea duty; some iron works have been established near Ulverstone since the opening of this canal.

Uppingham Canal. In 1793, it was proposed to make a canal from the town of Uppingham in Rutlandshire, to connect with the *Leicestershire and Northamptonshire Union* canal, and provision is made in its act (33 Geo. III.) for such junctions.

USKE RIVER. The direction of this river is nearly N. for about 4 miles in the county of Monmouth; the tide flows through its whole length; its objects are the export of coals, iron, &c. and the trade of Newport; at Pill-Gwnelly it connects with the *Monmouthshire* canal, and with the *Sir-becy* tram road; it commences in the *Severn* river at Nash, and terminates at Newport bridge.

Wakefield and Hull. In September last (1805) notices were given for a rail way from the *Calder and Hebble* navigation at Bottom boat in Wakefield, to Hullet-hall collieries, with branches to Birstal and Smithic bridge in the west riding of Yorkshire.

WARWICK AND BIRMINGHAM CANAL. Acts 33 and 36 of Geo. III.—The general direction of this canal is nearly N.W. for 25 miles in the counties of Warwick and Worcester; it crosses the grand-ridge without a tunnel; its objects are the supply of Warwick with coals, &c. and forming part of the most direct water communication between Birmingham and London; at Kingwood in Rowington, this canal is joined by a branch from the *Straford* canal. Birmingham is the 6th British town with 73,670 persons, and Warwick is the 107th with 5,775 persons, on the line of this canal; which commences in the *Warwick and Naptun* canal in Budbrook parish near Warwick, and terminates in the Digbeth cut of the *Birmingham and Fazeley* canal at Digbeth near Birmingham; it has a cut of ¼ of a mile to

the basin at Saltesford in Warwick. From the *Warwick and Napton* canal, about $\frac{1}{2}$ a mile, to near Buddbrook town, is level; thence $2\frac{1}{2}$ miles to Hatton, is a rise of about 20 locks; thence to the Stratford branch, about 5 miles, is level; thence to Knowle common, about $4\frac{1}{2}$ miles, is level; thence to Knowle-wharf, 1 mile, is a fall of about 7 locks; thence to near Deritend, about 10 miles, is level; thence to the Digbeth branch of *Birmingham and Fazeley*, $1\frac{1}{2}$ mile, is a rise of about 5 locks. At the termination at Digbeth a stop-lock is erected, which the *Birmingham and Fazeley* company may fasten up, whenever the water in this canal is of less depth than 4 feet at such lock. At Haseley there is a tunnel of 300 yards in length; at Henwood wharf there is an aqueduct over the Blythe river; near Flint Green another over the Cole river; and near its termination at Digbeth another over the Rea river. In May 1796, the northern end of the canal for near 9 miles to Henwood aqueduct was completed and opened; and, on the 19th of December 1799, the whole line was completed and opened. On the 30th of April 1799, a bank of this canal broke, it was said, and the flow of the waters did some damage. This company was authorized to raise 180,000*l.*, the amount of their shares is 100*l.* each. The rates of tonnage will be found in Mr. *John Cary's Inland Navigation*, pages 56 and 57; paving-stones, road-materials, and manures for adjoining lands (except lime), are to pass free on the pounds, or through the locks when the water runs waste. Husbandry boats, not exceeding 5 feet wide, may be used by occupiers of lands; boats less than 70 feet long, or with less than 20 tons of lading, are not to pass the locks without leave. The *Birmingham and Fazeley* company are allowed to take 6*d.* per ton on all goods which pass from that canal to this, until they have paid off 3,600*l.* of their debt, after which they are to take only 5*d.*; they are also allowed 3*d.* per ton on all goods passing from this canal to that.

WARWICK AND NAPTON. Act 34 and 36 Geo. III.—The general direction of this canal, (at first called the Warwick and Braunston,) is nearly East, for about 15 miles, in the county of Warwick: it is considerably elevated, and terminates near to the grand-ridge, on its West side: its main object is, the opening of the most direct line between Birmingham and London. Warwick is the 107th British town, with 5,775 persons; Southam is also a considerable town near to this canal; which commences in the *Warwick and Birmingham* canal, in Buddbrook parish near to Warwick, and terminates in the *Oxford* canal at Napton on-the-hill; near Warwick it crosses the Avon river, on an aqueduct bridge; near Radford and Long-Itchington there are smaller aqueducts. This canal is level with the *Warwick and Birmingham* canal at their junction, and is entitled to the waste water from that canal. This canal was completed on the 19th of December 1799. The company were authorized to raise 130,000*l.*; the amount of each share being 100*l.*, but by the last act above, the holders of the original 1000 shares, were authorized to contribute any further sum, and to be entitled to a proportionate dividend, with original shares, on such addition. The tonnage rates are adapted to the principle, of making goods pay a higher rate for short distances; see *John Cary's Inland Navigation*, pages 59 and 60: paving-stones, road-materials, and manures for the adjoining lands, (except lime,) are to pass free on the pounds and through the locks when the water runs waste thereat. Boats less than 70 feet long, or with less than 20 tons of lading, are not to pass the locks without leave. The *Oxford* canal company are entitled to a variety of rates on goods passing out of this canal into that, which see in *Cary* as above.

WAVENEY RIVER. The general direction of this river

is nearly S.W. by a bending course of about 2½ miles, between the counties of Suffolk and Norfolk: it is not greatly elevated in any part; its objects are the import of coals, deals, &c. and export of agricultural products: Yarmouth is the 28th British town, with a population of 14,845 persons; Beccles and Bungay are also considerable towns, on or near this river; which commences in the *Tare* river at Burgh, and terminates at the town of Bungay.

WEAR RIVER. Act 34 Geo. II.—The general direction of this river is nearly S.W. for about 10 miles in the county of Durham; it is not greatly elevated in any part; its principal object is the export of coals. Sunderland is the 34th British town, with 12,412 inhabitants; Durham is the 74th, with 7,520 persons; and Bishops-Wearmouth is the 97th, with 6,126; Monks Wearmouth and Chester-le-Street are also considerable towns, on or near this river; which commences in the German ocean at Wearmouth near Sunderland, and terminates at Lumley castle. There is a rail way of 7 miles in length from this river to Eaton-Main colliery, and a great number of others of considerable lengths, for conveying coals to the staiths and spouts where barges and ships are loaded with them. Eighteen different sorts of coals, or rather the produce of so many different pits, are usually shipped from this river for the London market, amounting in the whole to 105,000 chaldrons annually; see *Edington's Essay on the Coal trade*, page 31. In 1761, Mr. *John Smeaton* was consulted, about the building of the first lock on this river near Harraton; the linking of its foundations being thought to endanger the coal-mines which were working under the river at that place, the river was then to be deepened and made navigable, from Briddick-ford to the new bridge, the estimate being 3700*l.* In the year 1801, a new dry or graving-deck was hewn out of the rock on the North side of the river in Monk-Wearmouth. On the 6th of August 1796, a grand iron bridge of one arch, 230 feet span, and 100 feet high above high-water mark, was completed over this river at Wearmouth near Sunderland, as we have already mentioned in this article, and in our article BRIDGE. The importance of this bridge, besides its advantage in admitting ships further up the river, will appear from the tolls for passing over it, having been let for the current year at 2080*l.* At the mouth of this river there are two piers for the improvement of Sunderland harbour; in 1802, a new light-house, 70 feet high, was built on the North pier, furnished with reflecting lamps: during tide-time every night, another light is exhibited below the principal one, as a notice to ships of the proper time to enter the harbour. In 1797, and again in 1800, the *Durham and Chester-le-Street* canal was proposed to join this river near Chester, and thence extend the navigation to Durham.

WEAVER RIVER. Acts 7 Geo. I. and 34 Geo. II.—The general direction of this river is nearly S.E. by a crooked course of 20 miles in Cheshire: it is but little elevated in any part; its objects are the import of coals and Cumberland red iron-ore, and the export of salt and agricultural products: Frodsham, Northwich, and Middlewich, are considerable towns near this river; which commences in the *Mersey and Irwell* navigation, near Wellon, and terminates at Winsford bridge: the rise is about $45\frac{3}{4}$ feet by 10 locks: the boats are from 50 to 100 tons burthen: the trustees for this navigation were authorized to borrow money at 5 per cent. interest, and 1 per cent. for the risk; in 1759, the debt amounted to 20,200*l.*, borrowed at 5 and $4\frac{1}{2}$ per cent.: this debt has long ago been paid off; and, there being no private interest in the concern, to the amount of 3000*l.* has been paid in some years, to the county treasurer of Cheshire, to be laid out in amending and repairing the public bridges,

and in the repair of high-ways leading to the salt-works, agreeable to the directions of the first act. The salt-mines at Northwich are 300 feet deep. In 1804, it was in contemplation to make a side-cut to this river, from near Frodsham, into the *Mersey* at Welton or Western point, for avoiding the bar or shoal at the mouth of this river.

WELLAND RIVER. Act 34 Geo. III.—The general direction of this river is nearly S.W. for about 37 miles in the county of Lincoln, and skirting the county of Northampton; it is not much elevated above the sea in any part; its objects are the import of coals, deals, &c. the export of Ketton free-stone, Collyweston white slates, agricultural products, &c.; near Crowland it connects with Catwater, a branch of the *Ken* river. Boston is the 102d British town, with 5,926 inhabitants; Spalding, Crowland, Market-Deeping, and Stamford, are also towns of some note on this river; which anciently was navigable for considerable vessels, from Fossdike-wash to Spalding; but owing to the constant changes, which have been taking place in these surprising fens, and their outfall into the wash, we learn, that in 1618, there was not 6 inches' depth of water at low tide in the channel, 2 miles below Spalding; so that when the commissioners of sewers inspected the same, their boat was obliged to be carried in a cart upon the sands for 3 or 4 miles below that town. In 1721, Mr. Nathaniel Kinderly (see his *Ancient and Present State*, &c. page 83) recommended the cutting of a new channel, from near the mouth of Glen river to Wyberton near Boston, by which the outfall of this river would be into the channel of the *Witham* river, instead of Fossdike wash. The subsequent contractions of the *Welland* river, by embankments near its mouth, somewhat improved the navigation to Spalding, and delayed until the year 1794 the adoption of Mr. Kinderly's proposed cut: in future the commencement of this navigation is to be in the tide-way of the *Witham* river at Wyberton roads, and it terminates at Stamford bridge. The new cut is to commence near the Ship alchouse in Wyberton, where there is to be a sea-fluice against the *Witham*, for the river and flood waters, with gates pointing to sea and to landwards; the threshold of this fluice is to be one foot below low water mark, and it is to be 50 feet wide in the clear; adjoining to the fluice is to be a tide-lock, for the use of the navigation, 60 feet long, and 8 feet wide, in the clear. From this sea-fluice, the cut is to be continued westward, with a regular ascent in its bottom, to 4 feet below the sill of Vernat's fluice, and is to terminate in the old *Welland* river, near Hooton's Gibbet: the width of the bottom of this new cut is to be 50 feet, and the sides are to batter 2 feet for 1 in height; at the distance of 50 feet from the edge of this cut on the South side, and 30 on the North side, banks 11 feet in height are to be made, to retain the floods and prevent their overflowing the adjoining fens, a precaution which has been adopted through the whole course of the fens. Messrs. *John Hudson*, *George Maxwell*, and *Edward Hare*, are appointed commissioners for setting out, and employing proper persons to execute the new cut, sluices, locks, &c. and are to cleanse the channel of the *Welland* for some distance above the new cut, and erect a sufficient dam across the river below the entrance of the same, at Shepherd's hole, to stop the tide waters and turn the land waters through the new cut; the rates of tonnage for navigating of which, will be found in *Phillips's 4to. History*, App. page 179. A bridge is to be built over the new cut at Fossdyke Inn: at Crowland, there is a most ancient and curious bridge on this river, springing from three different abutments, and meeting in the middle. See our article **BRIDGE**. In 1797, it was stated that 10,000l. had been subscribed for carrying the above new cut and improve-

ments into effect; and we hope that ere long the same will be completed. Trustees are appointed in the above act, for receiving the tolls and maintaining the works when completed by the commissioners. The greater part of the course of this navigation from Spalding to near Peakirk upwards, and from Market-Deeping to Stamford, is by modern cuts, on the north-west side of the old river, for avoiding its imperfect channel.

Wellspring and Leominster. About the year 1794, a canal was proposed from the *Montgomery* canal and *Severn* river near Wellspring, to the *Leominster* canal at Woferton; passing Bishops-Castle and Ludlow in its course.

WEY RIVER. The general direction of this river, is nearly S.S.W. for 20½ miles in the county of Surrey: it is not greatly elevated; its objects are the import of coals, deals, &c. and the export of chalk and agricultural products; at Wexley near Weybridge, it is joined by the *Basingstoke* canal. Godalmin, Guilford, and Chertsey, are considerable towns on or near to this navigation; which commences in the *Thames* river at Ham-Haw near Weybridge, and terminates at the town of Godalmin. From the *Thames* to Guilford bridge, 15½ miles, is a rise of 86½ feet; in this part the channel of the river was very early improved by side-cuts, and pound-locks, (said to be among the first erected in England, and to have been introduced by Sir *Richard Weston*); from Guilford bridge to Godalmin, is a canal 5½ miles, with a rise of 32½ feet; which is supplied by a feeder from the Wey at Godalmin. In 1791, and again in 1803, this navigation was proposed to be joined near Godalmin by a canal from the *Itchen* river, (see *Portsmouth and Croydon*). In 1800, the *Grand Surrey* was proposed to be extended to this river near Wexley; and in 1802, a branch from the *Grand Junction* canal was intended to connect with this river by means of the *Thames* at Ham-Haw.

WHARFE RIVER. The general direction of this river is nearly N.W. for about 9 miles, between Ainsty Liberty and the West Riding of Yorkshire: it is not much elevated above the level of the sea: its objects are the carriage of coals, free-stone, &c. and the export of agricultural productions. Tadcaster and Cawood are considerable towns on or near to this river, which commences in the *Ouse* river near Cawood, and terminates at the town of Tadcaster.

WHITEHAVEN BROOK. This brook is navigable but a very short distance, in a S.E. direction at its mouth, which is wide, constituting the harbour of Whitehaven in Cumberland: its chief object is the export of coals, lime, and free-stone. This harbour, situate on the Irish sea, has had several acts passed for its improvement, viz. 7 and 10 Anne, 13 Geo. II., 1, 2, 28, 32, and 45 Geo. III. and in September last (1805) notices were given for a further application to parliament. Whitehaven is the 62d British town with 8,742 inhabitants. Mr. *John Smeaton* was consulted in 1768, on the building of a north pier, and extending the southern one within 200 feet of it. In 1796, a violent storm happened, which considerably damaged the quays of this harbour. There are several rail-ways from this harbour, to the famous coal-mines in its vicinity. On the 4th of August 1738, the first rail or waggon-way was opened at this place, leading to Harthwaite and Woodhouse collieries. In 1802, the Hensingham lime-works were opened. On the 9th of August, 1803, the rail-way, 700 yards in length, passing over Branfryarch, or Road-bridge, to Howgill and Whingill coal-mines, were opened: and in the same year those to Brackenthwaite mine were opened. On 23d March last (1805) the William Pit, at 750 yards distance from the north wall of the harbour, was opened. Some of the veins of coals in these pits are 7½ to 12 feet thick, and from the whole of them 900 tons or upwards of coals are raised daily: one of these

mines extends $\frac{3}{4}$ of a mile under the sea, at about 600 feet beneath its bottom; inclined planes, 200 fathoms long, being used, for drawing up boxes of coals and others of water, from the extremities of these workings under the sea, to the bottoms of the shafts; these boxes are drawn up the planes by horse gins; for which purpose, and dragging the coal-waggons to the shafts, 100 horses are constantly employed under ground in these pits. The fire-damp often proves fatal to the men and horses employed in these works. There is a fine white free stone quarry on the west side of the harbour.

Wibsey and Dewsbury. In 1802, a rail-way was proposed from the *Calder and Hebble* navigation at Ravens-bridge in Dewsbury, to Low-moor iron-works in Wibsey, about 7 miles in length.

Wilden and King's-Bromley. In 1760, the line for a canal was surveyed by Mr. James Brindley and Mr. John Smeaton, from the *Trent* river at Wilden-ferry to King's-Bromley near Litchfield, 25 miles, with a rise of 110 feet by 19 locks, with a branch therefrom to Loughridge near Burflum, $30\frac{1}{2}$ miles, with 106 $\frac{3}{4}$ feet rise, by 28 locks; from which last a level branch was again proposed of $3\frac{1}{2}$ miles, to Newcastle-under-line: another branch of $2\frac{1}{2}$ miles, to Litchfield mill-pool, 18 feet rise, and 3 locks, and thence $\frac{1}{2}$ a mile farther with 30 feet rise, and 5 locks: another level branch was proposed of 10 miles, to Fazeley near Tamworth, and thence $\frac{1}{2}$ a mile, to the Tame river, 17 feet rise, by 3 locks. This canal was intended to be 24 feet wide, and 2 $\frac{1}{2}$ deep, with fords instead of bridges: the estimate was 100,200*l.* Mr. Smeaton suggested an extension of this canal, over Harecastle-hill, by deep-cutting, with reservoirs and steam-engines, for supplying the summit. The *Trent and Mersey*, *Newcastle-under-line*, and *C Coventry* canals have since accomplished what this scheme had in view.

WILTS AND BERKS CANAL. Acts 25 and 41 Geo. III. —The general direction of this canal is nearly N.E. by a bending course of about 52 miles, in the counties of Wilts and Berks: it crosses the grand ridge at the foot of the chalk-hills without any tunnel: its objects are the import of coals from both its extremities, the export of farming products, &c. Abingdon, Wantage, Swindon, Wotton-Basset, Chippenham, Calne, Melksham, and Trowbridge, are considerable towns on or near to this canal, which commences in the *Kennet and Avon* canal at Semington, and terminates in the *Thames and Isis* navigation at Abingdon. It has a cut of about $1\frac{1}{2}$ mile to Chippenham, one of about 3 miles to Calne, and another of about 1 mile to Wantage: the summit-level extends from near Wotton-Basset, to near the extremity of Wilts. The locks are calculated for long, narrow boats. On the Calne branch there is a short tunnel, under the road at Cuninghams park; and a principal aqueduct-bridge over Broadtown brook near Wotton-Basset. The rise of the road over the canal bridges is nowhere to exceed 3 inches in a yard; the springs and streams within 2000 yards may be taken; the use of inclined-planes instead of locks is provided for in the act; but they will not be necessary, the canal being generally cut through clayey soils that have plenty of water: half-mile stones are to be erected on the canal banks. The company have been authorised to raise 311,900*l.* the amount of shares being 100*l.* each. The inhabitants of Calne made an offer, in August 1799, we are told, to cut the branch to that town, on being allowed the tolls thereon for so doing. In August 1799, the western end of the line was completed and filled, and on the 1st May 1801, by the completion of the *Kennet and Avon* to Semington, the junction was formed, and 22 miles of the line to the aqueduct near Wotton-Basset, with the Calne and Chippenham branches, have since been used, prin-

cipally in bringing in Somersetshire coals. In September 1800, two branches of the *Thames and Severn* canal, by Faringdon and Highworth, were proposed, to join this canal at Uffington and Shrivvenham. In 1803, the Aylesbury branch of the *Grand Junction* canal was proposed to connect with this canal by means of the *Isis* river at Abingdon.

Winston and Stockton. In 1768, Mr. James Brindley and Mr. Robert Whitworth surveyed the line for a canal from the *Tees* river at Stockton in Durham county; passing Hartburn, Cothams-flob, Moor-house, Oak-tree, Maiden-dale, Bank-top, Darlington, Cockerton, Lower-Walworth, Legg's cross, Kullerby, and Staindrop, to Winston: with a branch $1\frac{1}{2}$ mile from Lower-Walworth to the *Tees* at Pierle-bridge; another from Darlington, 3 miles to Croft-bridge on the *Tees*; and another from Cothams-flob, 2 miles to the *Tees* at Yarm. The rise from Stockton to Winston is 328 feet. A feeder was to be taken from the *Tees* river, 3 miles above Winston. The export of coals, lime, and lead, was the object of this proposed canal.

WISBEACH CANAL. Act 34 Geo. III.—The direction of this canal is nearly S.E. for 6 miles, in the counties of Cambridge and Norfolk; it is but very little higher than the sea, being embanked through the level fens: its object is a communication between Wisbeach and Lynn, instead of an old part of the *Nen* river near it, which is almost grown up. Wisbeach is the only considerable town near this canal, which commences in the *Nen* river at the old sluice in Wisbeach, and terminates in the *Nen* river again at Outwell (at the commencement of Well-creek, a branch of that river leading to the great *Ouse* river): it is straight and level, having flood locks at its extremities. This company were authorised to raise 20,000*l.* the amount of each share being 10*l.* All goods entering or passing out of this canal are to pay 3*d.* per ton, except government stores and baggage, road-materials, manures, and materials for the use of the Fen-Corporation: husbandry boats may also be used toll free, but not pass the locks. The commissioners for the *Nen* navigation are to have 100*l.* out of these tolls, and the remainder, after paying interest on the debt, is to be applied in the repair and improvement of Well-creek.

WITHAM (old) RIVER. Act Geo. II.—The general direction of this river is nearly N.W. for about 41 miles in the county of Lincoln; it is but little elevated above the sea in any part: its objects are the import of coals, deals, &c., the export of farming products, and forming part of the inland communication between Lynn and Hull, Liverpool, Manchester, &c. Near Tattershall it is joined by the *Horncastle* navigation; at Chapel-hill by the *Stearford* navigation; and at Wyberton roads the new outfall and navigation of the *Welland* river are to join this river. Lincoln is the 76th British town, with a population of 7,398 persons, and Boston is the 102d, with 5,926 persons; Tattershall is also a considerable town near this river; which commences at the Scap or Scalp in the tide-way of Boston deeps in the Wash, and terminates in the *Fossdyke* canal, or new navigation at Brayford Meer. This river below Boston, about 4 miles, was anciently so deep, and was so much frequented by ships, that in the 6th year of king John, when the merchants of London paid only 83*l.* as a tax on their lands and goods, Boston contributed 780*l.* A gradual decay and silting up of the channel and harbour took place to such a degree, that when in 1761 Messrs. John Grundy, Langley Edwards, and John Smeaton examined the state of this navigation, and of the drainage of the adjoining fens, through which this river is embanked on both sides through nearly its whole length, owing to the long neglect of the banks, which should have confined the returning tide and the land-waters, so as to scower the channel, they reported that 30

ton barges could then scarcely reach Boston, while the navigation above that town was entirely lost, and the ancient channel was in several places entirely grown up and abandoned by the water, in its ordinary state. Mr. Smeaton then recommended the erection of a sea-luice upon this river below Boston, the sill thereof as low as low-water, with 3 openings, amounting to 50 feet wide; these to be furnished with doors pointing to sea-ward, and draw-gates behind them gauged, or having their tops, two feet below the surface of the fens, for always retaining a proper quantity of water in the river in dry seasons; also a sea-lock at the same place for the navigation, furnished with three pair of gates, two of them pointing to the land and one to the sea: the straightening, enlarging, and deepening of the river above Boston to 80 feet at top, 50 at bottom, and 10 feet deep, were recommended, and the erection of three pound-locks, furnished with flood-gates or opening-weirs adjoining, below Lincoln, and one other such lock above. The estimate for such of these works as related to draining, was 38,000*l.*, and for the navigation works 7,370*l.* It was remarked that Lincoln high-bridge had but 15½ feet clear width of water-way, above which a hard gravelly place, probably an ancient ford, called Brayford head, covered frequently with only 3 feet of water, acted as a weir for holding up the waters of Brayford meer and the *Fossdyke* canal. When Mr. Smeaton was afterwards consulted in the year 1782, he objected to a navigation lock which had been in the interim erected below Lincoln town, and recommended the cutting off the communication between *Fossdyke* canal and Brayford meer, by a pound-lock with gates pointing to the canal, and to deepen this river through and above Lincoln bridge, and to remove Brayford head, so as to lower the water in Brayford Meer: the principal wharfs appear to have been since made, and the trade of Lincoln is now carried on upon this meer or water. By the act of 32 Geo. III. for *Horncastle* and *Sleaford* navigation, those companies were required to contribute equally with this company in the expences of deepening and improving this river through Lincoln high-bridge, and thence to the *Fossdyke* canal, in the next 7 years; in consequence of which, goods passing on this river to or from the *Horncastle* or *Sleaford* navigations, are to pay only half the accustomed rates on this river. In 1803 it was in contemplation to further improve the navigation of this river below Lincoln. Much has been written on a prohibition said to exist against the shipping of coals from this river, on account of its preventing a rivalry with Newcastle and Sunderland coals in the London market, by the produce of the Yorkshire, Derby, and Nottingham mines being brought by the *Trent*, the *Fossdyke*, and this navigation, to Boston deeps; an expectation not much better founded, we fear, than that the opening of the *Stover* canal would have any effect on the London coal-market.

WORCESTER AND BIRMINGHAM CANAL. Acts 31, 38, and 44 of Geo. III.—The general direction of this canal is nearly N.E. for 29 miles in the counties of Worcester and Warwick; it crosses the grand-ridge by a tunnel: its objects are the export of coals, and a more direct communication between Birmingham and the *Severn* river: at Selly Oak it is joined by the *Dudley* canal, and at Kings Norton by the *Stratford* canal. Birmingham is the 6th British town, with a population of 73,670 persons; Worcester is the 40th, with 11,325 persons; Bromsgrove and Droitwich are also considerable towns near this canal; which commences in the *Severn* river at Diglis just below Worcester, and terminates in the old *Birmingham*, and the *Birmingham* and *Fazeley* canals, at their junction at Farmers bridge at the upper end of the town of Birmingham. From the *Severn* to Tardebig, 15 miles, is a rise of 428 feet by 71

locks; thence to the *Birmingham* canal, 14 miles, is level. The width of the canal at top is 42 feet, and the depth is 6 feet; the locks are 80 feet long and 15 feet wide; the boats are of 80 tons burthen. At Worcester there is a very fine basin for the canal boats. There are 4 or 5 principal, and several smaller culverts: the principal tunnel at West-Heath is 2700 yards long, 18 feet high, and 18½ feet wide within the arch, the depth of water therein is 7½ feet; at Tardebig is another of 500 yards in length; at Shortwood is another of 400 yards in length; at Oddingley one of 120 yards; and, at Edgbaston another of 110 yards in length: four of these tunnels are upon the summit-pound. Near Coston-Hacket there is an immense piece of deep cutting; in 1754, Mr. Carne's machine worked by a horse at length, was used for excavating the soil, instead of wheeling it out in barrows. Where the summit-pound of this canal connects with the *Birmingham*, the *Dudley*, and the *Stratford* canals; stop-locks are erected, which the several companies may shut and lock up, when the supplies of this or the other canals fail, so as to endanger the lowering of the summit-pound, to obstruct the navigation. Mr. John Smeaton was one of the engineers to this canal, the scheme of which was laid, and a bill was brought into parliament in 1790, but the opposition of interests, and natural difficulties of this vast undertaking then proved fatal to it; the great anxiety and fatigue which Mr. Smeaton underwent in this arduous undertaking, are thought to have injured his health and to have shortened the days of that very able and excellent man. In May 1796, the eastern end of this canal, as far as the *Stratford* canal at Kings-Norton, was completed. The arching of the West-heath tunnel was begun on the 28th of July 1794, the whole of it was turned by the 25th of February 1797, (1780 yards of it having been completed in the year 1796) and in March 1797, the navigation was extended through it to Hopwood wharf, and in the following year, the same was extended to the western end of the summit-pound at Tardebig. The company were authorised by their two first acts to raise 399,929*l.* 1*s.* 1½*d.*: their whole shares being made hereby, of the odd value of 138*l.* 17*s.* 9*d.* each: these were said to be depreciated in value almost to nothing; but in 1802, they had risen to 40*l.* each. The last act was for raising a further sum of money for completing the very difficult part of the line, and supplying lockage-water, by steam-engines to pump it up from the *Severn*, by reservoirs, &c. which yet remains to be accomplished. The rates of tonnage owing to the several junctions with neighbouring canals are very complicated; see *Cary's Inland Navigation*, pages 68 to 70. Two-pence per ton is charged on goods entering the Worcester basin from the *Severn* river, to be there unloaded. This company guarantees the future profits of the *Droitwich* company to the extent of 5 per cent. annually on each share, and those of the *Stourbridge* company to 9*l.* per cent. on each share: they are also to compensate the water-bailiff of Worcester for his dues on coals sold on the *Severn* at Worcester; they are also to pay to George Perrot esq. as owner of the *Stratford Avon* navigation, 400*l.* per annum for loss of his tolls on the upper part of that river by the making of this and the *Stratford* canal, besides making up any deficiency there may hereafter be, in his rents of 1227*l.* for the tolls on the lower part of that river. About the year 1795, a branch was proposed, it appears, from this canal near Hanbury-Hall to the *Droitwich* canal at that town.

WYE RIVER. The general direction of this rapid and romantic river is nearly N.W. by a very bending and crooked course of about 85 miles, in the counties of Monmouth and Hereford, and Brecknock, in South Wales, and skirting

CANAL

the county of Gloucester: its northern end is considerably elevated: its objects are the carriage of coals, and the export of agricultural products; at Hereford it is approached very near, if not joined, by the *Hereford and Gloucester* canal. Hereford is the 89th British town, with a population of 6,828 persons: Chepstow, Colford, Monmouth, Ross, and Hay are also considerable towns on or near to this river; which commences in the *Severn* river at Beachley, and terminates at the town of Hay. The tide often rises in the mouth of this river, to the extraordinary height of 40 feet; Chepstow bridge over the same, is of great height above the water at low tide. In 1802, and again in 1804, it was in contemplation to make a horse towing-path by the side of this river, and by deepening the shallows in several places to improve its navigation. In 1802, the *Dean-Forest* railway was proposed to join this river at English-Bichnor, we believe; in the same year notices were given, for an intended railway from this river at Hereford, to join the same again opposite to Lydbrook; and in March last (1805) another railway was proposed from this river to the *Monmouthshire* canal.

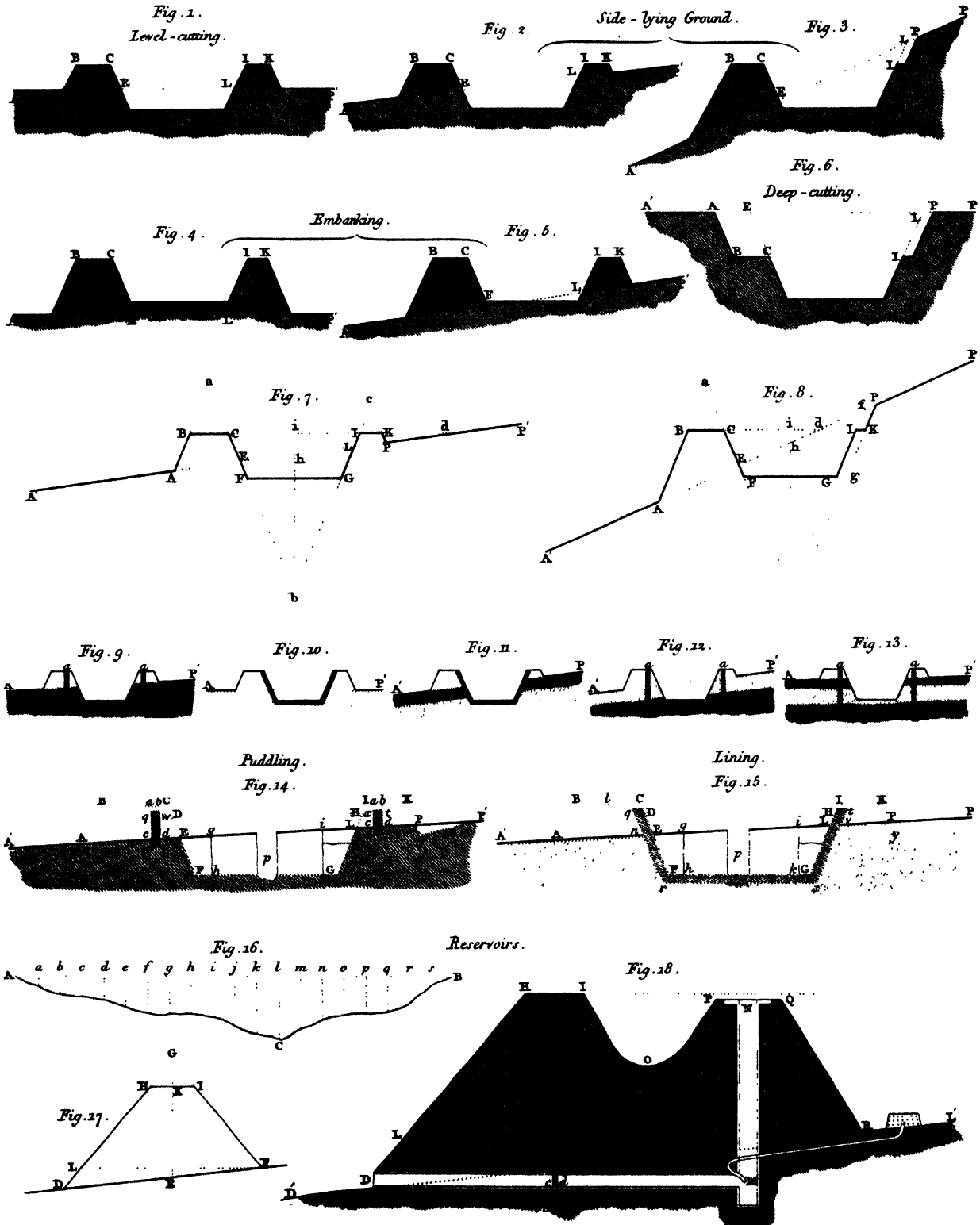
WYRLEY AND ESSINGTON CANAL. Acts 32 and 34 Geo. III.—The general direction of this canal is nearly S.W. by a very crooked course of 23 miles in the county of Stafford: it is considerably elevated, and terminates at its western end near, or upon the grand-ridge: its object is the export of coals, iron, and lime, which abound in its course: Wolverhampton is the 33d British town, with a population of 12,565 persons; Litchfield and Walsall are also considerable towns on or near to this canal; which commences in the detached part of the *Coventry* canal at Huddlesford (near to Whittington brook, and the commencement of the *Birmingham and Fazeley* canal) and terminates in the old *Birmingham* canal near Wolverhampton: there is a branch of $5\frac{1}{2}$ miles to Hay-head lime-works; another of $2\frac{1}{2}$ miles to Lord's-Hay coal-pits; another of near 4 miles at Wyrley-bank collieries, with a branch from this last near 1 mile to Essington new collieries; there is also a branch $\frac{1}{2}$ a mile to near Walsall town, which terminates within $\frac{1}{2}$ a mile of the branch of the old *Birmingham* thereto. From the *Coventry* canal to near Cannock-Heath reservoir, $7\frac{1}{2}$ miles, is a rise of about 264 feet, by 30 locks; thence to the old *Birmingham* canal, $15\frac{1}{2}$ miles, is level; the Lord's-Hay, Hay-head, and Walsall branches are all level with the long pound: the Wyrley branch rises about 36 feet, by 6 locks, in the first $\frac{1}{2}$ mile, the remainder thereof is level, and therefrom the Essington branch rises about 24 feet, by 4 locks. This canal is 28 feet wide at top, 16 at bottom, and $4\frac{1}{2}$ feet deep. No water is to be taken from the old *Birmingham* canal, but a lock is erected at the junction, and this canal is to be constantly kept 6 inches higher than that, or all boats are to be stopped, by a man stationed there for that purpose: the surplus water from this is to be vented into the old *Birmingham* canal. Litchfield water-works pipes were to be carefully guarded in cutting this canal. Branches of 5 miles in length may be made to this canal by the owners of the mines, if they waste no water. Mr. William Pitt was the engineer: and the canal and works were long ago completed. The

company were authorized to raise 160,000l. the first 35,000l. in 125l. shares; on the extension of the canal in 1794, the company were required to purchase the shares of certain discontented proprietors: the new shares are 100l. each. The rates of tonnage will be found in Mr. *John Cary's Inland Navigation*, p. 47 and 48. Less than 20 tons in a boat is not to pass the locks without paying for that lading, except empty boats on their return. In 1792, it was proposed to make a branch to Stow-heath, and two others into Ashmore-park.

YARE RIVER. The direction of this river is nearly W. by a bending course of about 42 miles, in the county of Norfolk: it is not much elevated in any part; its objects are the import of coals, deals, &c. and the export of agricultural products: at Yarmouth this river is joined by the *Thyrn* river, and at Burgh by *Waveney* river. Norwich is the 11th British town, with a population of 36,854 persons, and Yarmouth is the 28th, with 14,845 persons; there are no other considerable towns near this river; which commences in the German Ocean at Gorleston-fort, and terminates at the water-works and mill in Norwich: at Yarmouth there is a draw-bridge for admitting masted vessels above it. The quay of this port is $1\frac{1}{2}$ mile in length, and in some parts 150 yards in breadth: a curious kind of low carriages called Yarmouth-Carts are used for conveying the goods from the quay to the warehouses. In 1804, St. Michael's Collany bridge over this river in Norwich city was taken down, and a cast-iron bridge erected by Mr. *Froft* in its stead. In 1785, and again in 1802, the *London Lynn and Norwich*, or North London canal, was proposed to join this river at Norwich.

YORE RIVER. Act 7 Geo. III.—This river, sometimes called the Ure river, has nearly a N.W. direction for about $8\frac{1}{2}$ miles in the West, and skirting the North Riding of Yorkshire: its objects are the supply of Borough bridge and Ripon, and the export of agricultural products: at Myton it is joined by the *Swale* river. This navigation commences in the *Ouse* river at Linton, and terminates in the *Ripon* canal at Milby. From the *Ouse* to the *Ripon* canal, is a rise of 11 feet; at Linton river is a lock, and a dam or weir so made up as to allow about 1 inch per mile in this distance, for a stream navigation. Mr. *John Smith* was the engineer, who in 1767 referred to Mr. *John Smeaton* for his opinion on the height of Linton dam, and other matters relating to the works then going on.

For further illustrating this part of our subject, we intend to give a map of the British islands, sufficiently large to distinguish all the navigable rivers, canals, rail-ways, harbours, &c.; and having adopted a method, by which the inconveniences of large folding-maps will be avoided, and yet perfect facility be given, of reference from any page of the map to the other, this will probably be the first of a series of maps, for describing more particularly than has yet been done, several useful and curious particulars relating to the topography and present state of our own country.



CAST IRON AQUEDUCTS.

Mr. Telford's, on the Shrewsbury Canal at Long.

Fig 22

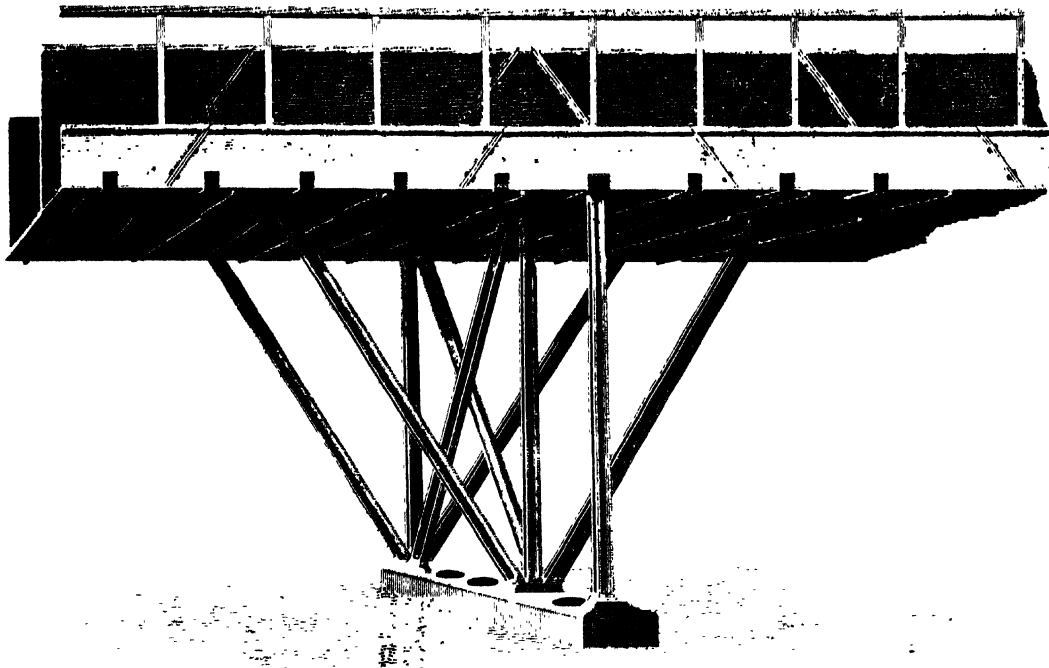
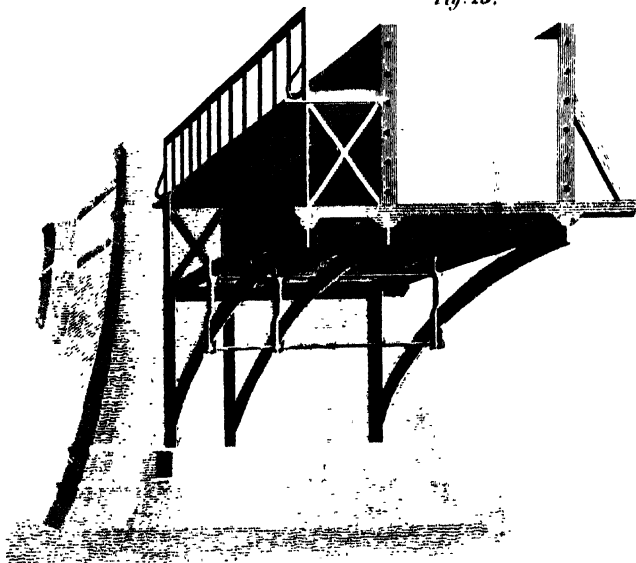


Fig. 23.



by Mr. Fulton.

Fig 24.

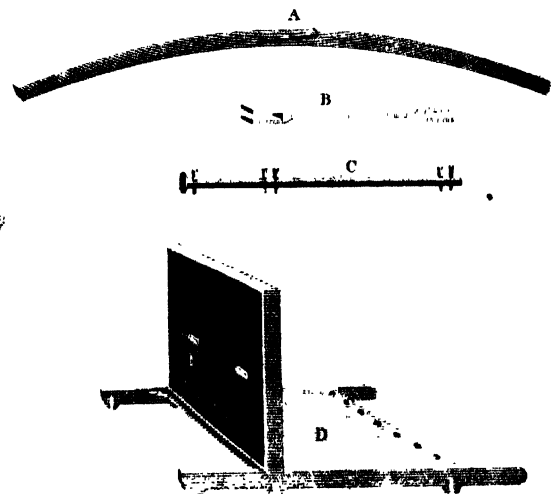


Fig. 25. Embankment

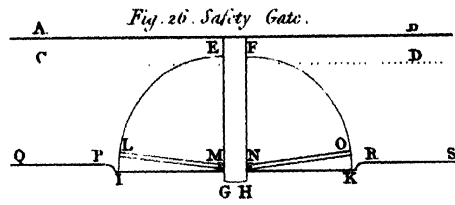
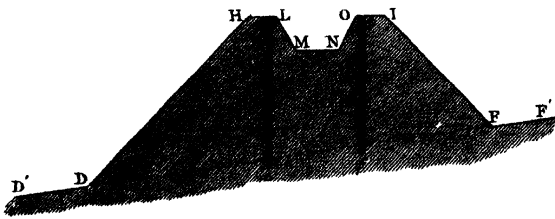


Fig. 27. Weir.

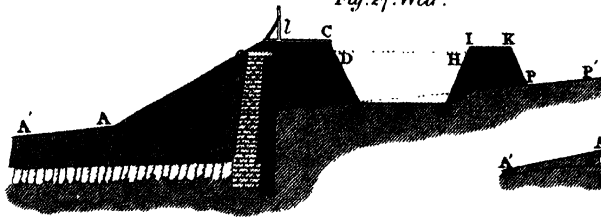


Fig. 28. Circular Weir.

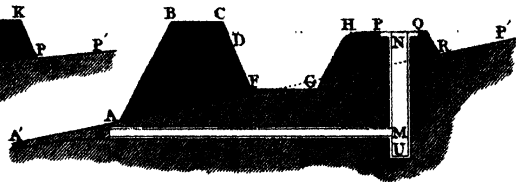


Fig. 29.

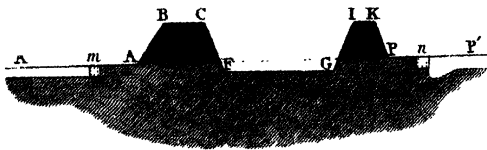


Fig. 30. Pile-planks

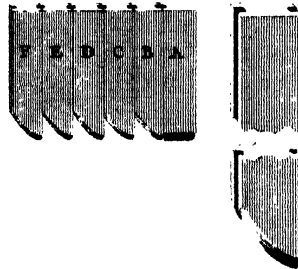


Fig. 31



Iron Rail-ways.

Fig. 34.



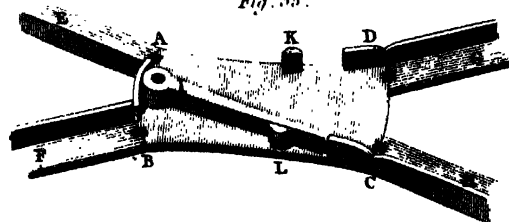
Fig. 32



Fig. 33.



Fig. 35.

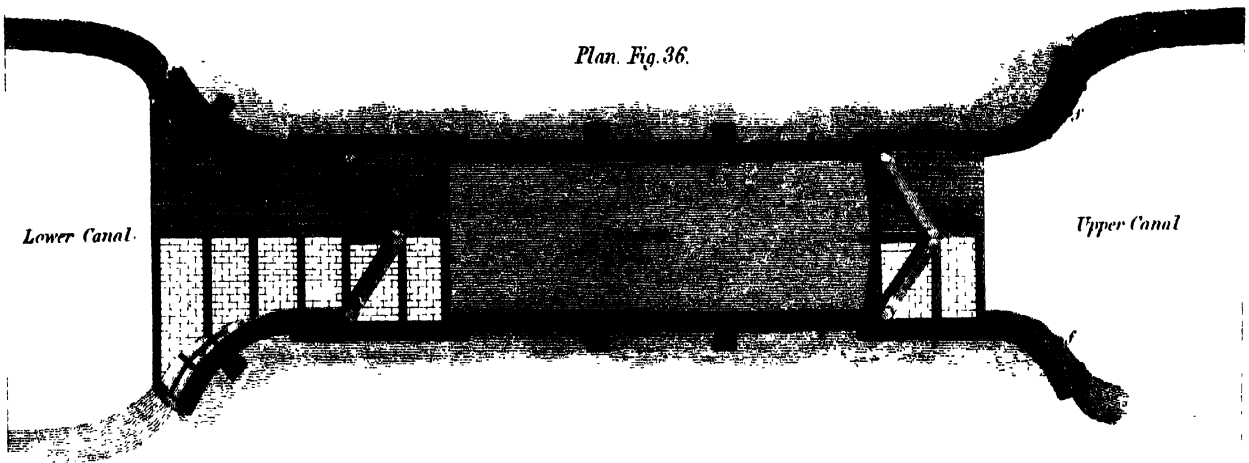


CANALS.

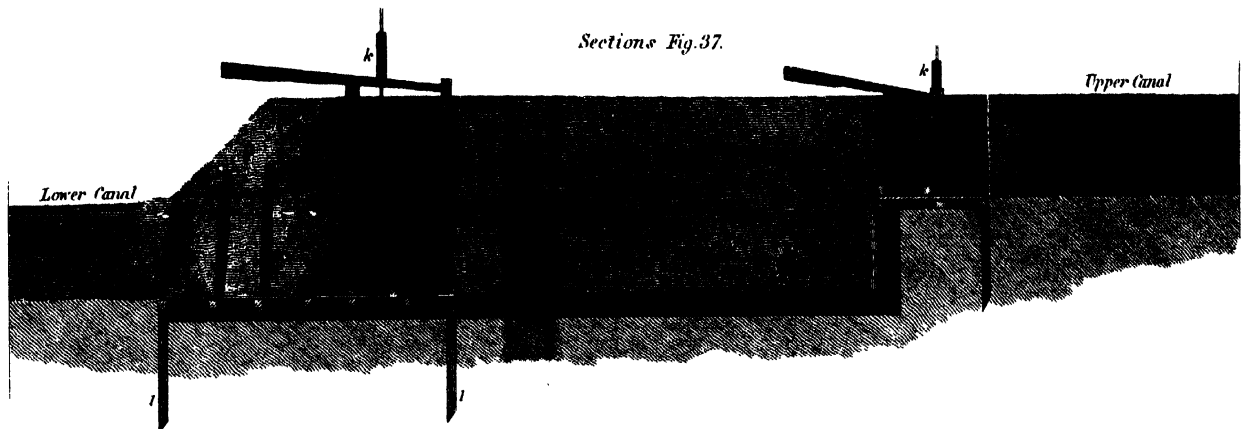
PLATE V.

LOCKS.

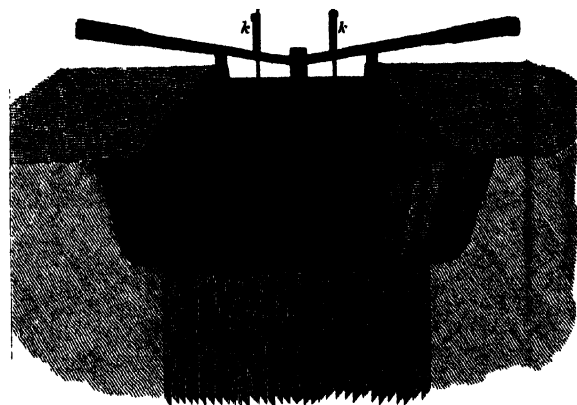
Plan. Fig. 36.



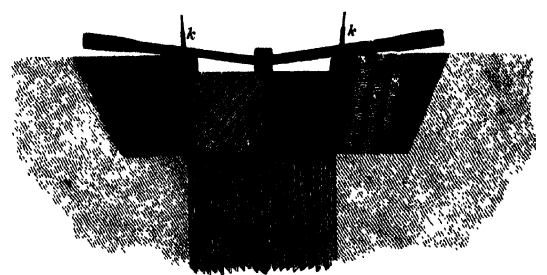
Sections Fig. 37.



Lower Gates Fig. 39.



Upper Gates Fig. 38.



CANALS.

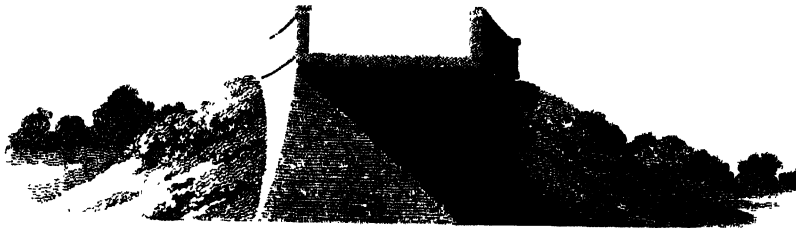
BRIDGES.

PLATE VI.

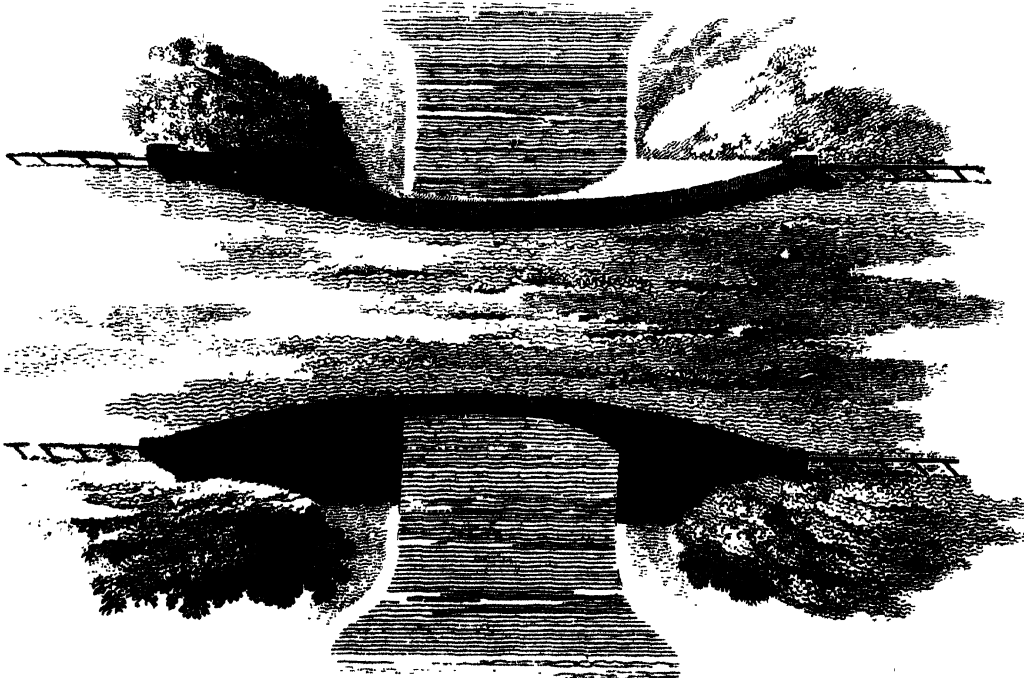
View Fig. 42.



Section Fig. 41.



Plan Fig. 40.



Swing Bridge

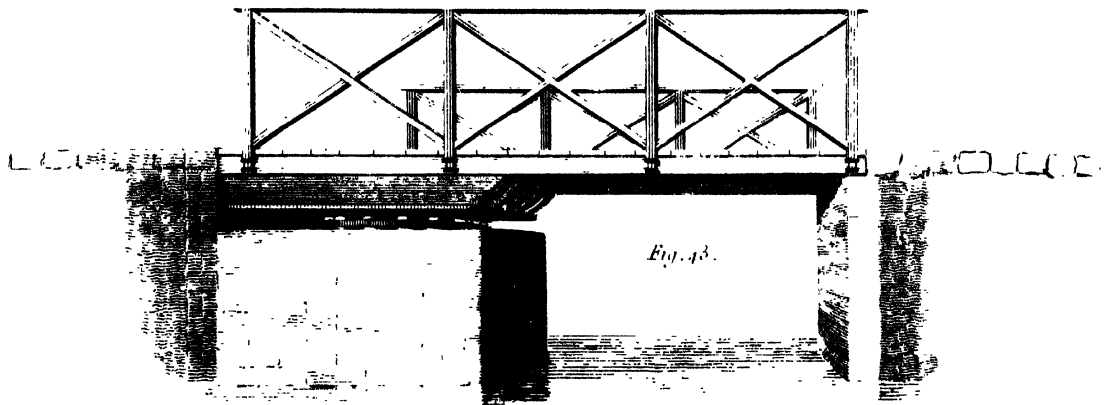


Fig. 44.

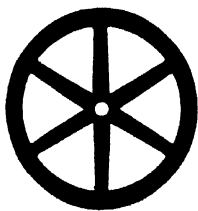


Fig. 45.



Fig. 46.

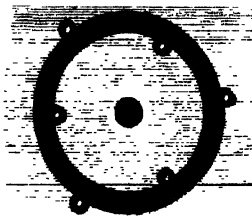


Fig. 47.



NAVIGATOR'S TOOLS &c.

Fig. 48. Barrow.

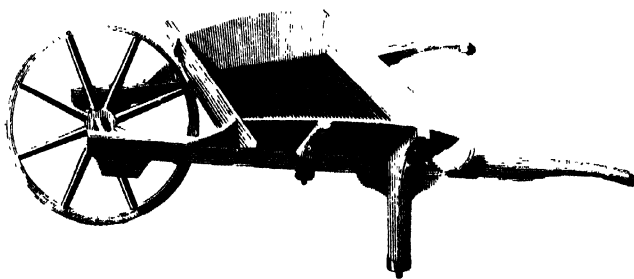
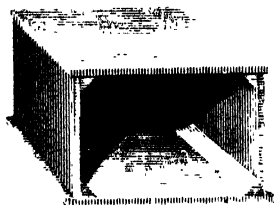


Fig. 52. Scoop.

*Fig. 50.
Grading Tool.*

*Fig. 52.
Shovel.*

Fig. 49. Horsing-Block.



Candle

CANDLE, a cotton or linen wick, loosely twilted, and covered with tallow, wax, or spermaceti, in a cylindrical figure; which, being lighted at the end, serves to illuminate a place in the absence of the sun.

The word *candle* comes from *candela*, and that from *candor*, of *candēs*, *I burn*; whence also the middle age Greek *κανδελιον*.

A tallow candle, to be good, must be half sheep's and half bullock's tallow; the fat of hogs makes them gutter, gives an ill smell, and a thick black smoke.

Tallow candles are of two kinds; the one dipped, the other moulded: the first, which are those in ordinary use, are of an old standing; the latter are said to be the invention of the sieur le Brez, at Paris. The manufacture of the two kinds is very different, excepting in what relates to melting of the tallow, and making the wick, which is the same in both.

CANDLES, method of making. The different kinds of tallow being weighed and mixed in their due proportion, are cut or hacked into pieces, to facilitate their melting, and thrown into a pot or boiler, having a cavity of some depth running round the top, to prevent its boiling over. Being thus perfectly melted and skimmed, a certain quantity of water is thrown in, proportioned to the quantity of tallow; this serves to precipitate the impurities of the tallow, which had escaped the skimmer, to the bottom of the vessel. The tallow, however, intended for the first three dips, must have no water; because, the dry wick imbibing the water readily, makes the candles spit and crackle in the burning. The melted tallow is now emptied through a sieve into a tub, having a tap for letting it out, as occasion requires. The tallow, thus prepared, may be used after having stood three hours; and will continue fit for use twenty-four hours in summer, and fifteen in winter. The wicks are made of spun cotton, which the chandlers buy in skeins; and they wind off three or four together, according to the intended thickness of the wick, into bottoms, or clues, from a certain number of which threads are

drawn off, and then cut with an instrument contrived for that purpose, into pieces of the size and length of the candle required. The machine for cutting the cotton consists of a smooth board adapted to rest on the knees; (see *Plate, Candle-Making, fig. 1.*) on the upper surface of which are the blade of a razor, or a knife, A, and a pin or round piece of cane, B, placed at a certain distance from one another, according to the length of the cotton that is wanted: the cotton is then carried round the cane, B, and being brought to the razor, or knife, A, is instantly separated from the several bottoms or balls. The next operation is that of "pulling the cotton," which is that of laying smooth the threads, removing all knots, &c. and thus rendering it fit for use. It is then put on the sticks, or broaches, or else placed in the moulds, as the candles are intended to be either dipped or moulded. The broaches are rods about half an inch in diameter, and somewhat more than three feet long.

CANDLES, making of dipped. The liquid tallow is drawn off from the tub above mentioned, into a vessel called the mould, sink, or abyss, of an angular form, perfectly like a prism, except that it is not equilateral, the side on which it opens being only ten inches high; and the others, which make its depth, fifteen. On the angle, formed by the two great sides, it is supported by two feet, and is placed on a kind of bench, in form of a trough, to catch the droppings, as the candles are taken out at each dip. At a convenient distance from this is seated the workman, who takes three sticks, or broaches at a time, strung with the proper number of wicks, viz. sixteen, if the candles are to be of eight in the pound; twelve, if of six in the pound, &c. and holding them equidistant, by means of the second and third finger of each hand, which he puts between them, he immerses the wicks two or three times for their first lay, and, holding them some time over the opening of the vessel to let them drain, hangs them on a rack, or frame, where they continue to drain and grow hard. When cooled, they are dipped a second

second time, then a third as before; only for the third lay they are immersed but twice, in all the rest thrice. The operation is repeated more or less times, according to the intended thickness of the candles. With the last dip they neck them; i. e. plunge them below that part of the wick where the other lays ended. Such as we have above described used to be the laborious method of making common candles; till within 15 or 20 years past, when an invention was introduced which served very much to diminish the labour and to facilitate the operation. This method of making dipped candles, as now practised by the manufacturers in London, is as follows: the wicks prepared as above are hung at equal distances upon the broaches; and when five of these are filled, they are put into holes in two pieces of wood, C, D, (*fig. 2.*); thus forming a frame full of wicks. The vessel, A, (*fig. 1.*) is then filled with melted tallow. This vessel is made of lead, and has a hole, B, under it for receiving a chaffing-dish to keep the tallow warm; on each side of the vessel are two leaves, C, D, for catching the droppings of the candles as they are dipped; over the vessel is suspended from the ceiling a framed lever, K, K, with two arched heads, L, L, at each end, in order to give a vertical motion to the scale, I, and frame, EFGH, the two cross pieces, E, F, of which are for the leaves, C, D, of *fig. 2.* to rest upon. The dipper then lays hold of the upper bar at G and H, and gently pushes down the wicks into the melted tallow, and keeps them down till he finds that, by the tallow adhering to them, they are heavier than the weight in the scale I, previously adjusted to the proper weight. The frame of candles is then removed and hung up to cool, which takes some days, according to the state of the weather. When they are quite stiff, they are dipped again with a heavier weight in the scale I, and this operation is continued, till they are of the proper size. The workman, by means of this simple contrivance, has only to guide the broaches and candles, and not to support the weight of them as in the old method.

It must be observed, that during the operation the tallow is stirred from time to time, and the stock supplied with fresh tallow. When the candles are finished, their peaked ends, or bottoms, are taken off; not with any cutting instrument, but by passing them over a kind of flat brazen plate, heated to a proper pitch by fire underneath, which melts down as much as is requisite.

CANDLES, method of making mould. These candles are made in moulds of different materials; that generally used is pewter. Each candle has its mould, consisting of three pieces, the neck, shaft, and foot: the shaft is a hollow pewter cylinder, B, (*fig. 6.*) having the end *a* somewhat smaller than the other, that the candle may slide out easily, of the diameter and length of the candle proposed; at the extremity of this is the neck, A, which is a little metallic cavity, in form of a dome, having a moulding withinside, and pierced in the middle with a hole big enough for the wick to pass through. At the other extremity is the foot, in form of a little tunnel, through which the liquid tallow runs into the mould. The neck is soldered to the shaft, but the foot is movable, being applied when the wick is to be put in, and taken off again when the candle is cold. A little beneath the place where the foot is applied to the shaft, is a kind of string of metal, which serves to support that part of the mould, and to prevent the shaft from entering too deep in the table to be mentioned hereafter. Lastly, in the hook of the foot, is a leaf of the same metal, soldered within side, which, advancing into the centre, serves to keep up the wick; which is here hooked on, precisely in the middle of the mould: The wick is introduced into the shaft of the mould by a piece of wire, which being

thrust through the aperture of the hook, till it come out at the neck, the wick is tied to it; so that in drawing it back, the wick comes along with it, leaving only enough a-top for the neck; the other end is fastened to the hook, which thus keeps it perpendicular, E E (*fig. 5.*) Ten or fifteen of these moulds, in this condition, are fixed in a frame pierced full of holes, the diameter of each being about an inch, by a screw at the top of each mould, which attaches them to the upper board B of the frame. This board has three upright sides and one sloping, which forms a small cistern for the tallow. When every mould in the frame has been provided with a wick, two wires, *cc*, (*fig. 5.*) are passed through the two ends of the cistern at the top of the frame, and the loops of the several wicks. The ends of the wicks which hang out of the mould are pulled tight, their tops are put over the centers of the moulds, and the friction of the mould keeps them in this position. These moulds are filled with tallow out of a cistern, A (*fig. 4.*) the outside of which is wood, and lined with lead; within which is another cistern of lead for containing the melted tallow, prepared as above, with about two inches space between them all round to be filled with hot water for keeping the tallow warm. In the bottom of the vessel are three small shuttles, B, C, D, communicating with the inner vessel, and serving to fill the moulds, E E, before described. After the frame is filled and the tallow has acquired its due consistence, the two wires, *cc*, are withdrawn, and the loose tallow in the cistern at the top of the frame scraped out; they are set out in the open air to cool, and when thoroughly cold, the candles are pulled out of the mould by a bodkin put through the loops of the wicks where the wires, *cc*, passed before.

Those who aim at perfection in their work, bleach or whiten their candles, by fastening them on rods or broaches, and hanging them out to the dew, and earliest rays of the sun, for eight or ten days: care being taken to screen them in the day-time from the too intense heat of the sun, and in the night from rain, by waxed cloths. Tallow-chandlers make other candles, which are intended to burn during the night without the necessity of being snuffed. The wick of these has been usually made of split rushes; but of late, very small cotton wicks have been substituted for the rush; these are much more easily lighted, are less liable to go out, and, on account of the smallness of the cotton wick, they do not require the aid of snuffers. The price of candles used formerly to be regulated by the masters and wardens of the tallow chandlers' company, who were accustomed to meet at their hall every month for the purpose; but now the price of every article belonging to the trade is fixed at the weekly markets.

CANDLES, wax, are made of a cotton or flaxen wick, slightly twisted, and covered with white or yellow wax. Of these there are several kinds; some called tapers, used to illuminate churches, and in processions, funeral ceremonies, &c. and others used on ordinary occasions.

As to the first kind, their figure is conical, still diminishing from the bottom, which has a hole to receive the point in the candlestick, to the top, which ends in a point: the latter kind are cylindrical. The first are either made with a ladle, or with the hand.

CANDLES, wax, manner of making with the ladle. The wicks being twisted, and cut off at the proper length, a dozen of them are tied by the neck, at equal distances, round an iron circle, suspended directly over a large basin of copper tinned, and full of melted wax: a large ladle full of this wax is poured gently, by inclination, on the tops of the wicks, one after another; so that running down, the

whole wick is thus covered; the surplus returning into the bafon, where it is kept warm by a pan of coals underneath it. They thus continue to pour on the wax, till the candle arrive at its destined size: still observing, that the three first ladles be poured on at the top of the wick, the fourth at the height of $\frac{3}{4}$, the fifth at $\frac{1}{2}$, and the sixth at $\frac{1}{4}$; by which means the candle arrives at its pyramidal form. The candles are then taken down hot, and laid aside of each other, in a feather-bed folded in two, to preserve their warmth, and keep the wax soft: they are then taken and rolled, one by one, on an even table, usually of walnut-tree, with a long square instrument of box, smooth at the bottom. The candle being thus rolled and smoothed, its big end is cut off, and a conical hole is made in it.

CANDLES, wax, manner of making by the hand. The wick being disposed, as in the former, they begin to soften the wax, by working it several times in hot water, contained in a brass caldron, tinned, very narrow and deep. A piece of the wax is then taken out, and disposed, by little and little, around the wick, which is hung on a hook in the wall, by the extremity opposite to the neck; so that they begin with the big end, diminishing still, as they descend towards the neck. In other respects, the method is the same here as in the former case; only that they are not laid in the bed, but are rolled on the table, just as they are formed. It must be observed, however, that in the former case, water is always used to moisten the several instruments, to prevent the wax from sticking; and in the latter, lard, or oil of olives, for the hands, table, &c.

CANDLES, wax cylindrical, are made either with the ladle, or drawn. The first kind are made of several threads of cotton, loosely spun, and twisted together, covered with the ladle, and rolled, as the conical ones, but not pierced.

CANDLES, wax, drawn, are so called, because actually drawn, in the manner of wire, by means of two large rollers, or cylinders of wood, turned by a handle, which turning backwards and forwards several times, pass the wick through melted wax, contained in a brass bafon; and at the same time through the holes of an instrument, like that used for drawing wire, fastened at one side of the bafon: so that, by little and little, the candle acquires any bulk, at pleasure, according to the different holes of the instrument through which it passes: by this method, may four or five hundred ells at length be drawn, running. The invention of this was brought from Venice by Pierre Blesimare of Paris, about the middle of the 17th century.

The ascent of the tallow up the wick in a burning candle, may be resolved into the same principle of filtration, or attraction, as that of water up a heap of ashes, or even up a capillary tube. The wick of a candle is but slightly twisted, that all its hairs may be easily come at; which being very small, soon take the flame: and the flame by its heat rarefying the air, and dissolving the tallow underneath, makes the globules thereof ascend into the rarefied spaces of the wick, and these, with the air about it, prove food for the flame.

A patent was granted in 1799, to Mr. William Bolts of London, for new modes of improving the form, quality, and use of candles. The most material alteration in Mr. Bolts's invention from the common method of making candles, consists in saving the greater part of the wick by rendering it moveable; and for this purpose it is kept constantly soaking in the tallow as it melts, so that the cotton is consumed very slowly as in lamps fed with oil. The patentee employs two methods for accomplishing this object; one is that of making candles entirely solid, without any wick passing through them; and applying the wick, which is very

short, upon the top of the solid candle, where it burns like that of a lamp; the heat which it affords when first lighted being sufficient to furnish the first supply of melted tallow, and to continue it as long as any part of the candle remains unconsumed. In order to keep the wick constantly applied, it is fastened to a small projecting spring, into which it is firmly fixed; and the surface of the candle is always kept in contact with the wick, either by causing the wick stand to pass round the candle like a collar, which moving freely on the candle, will sink in proportion as this is consumed, or by making the wick stand immovable, and putting a spiral spring at the bottom of the candlestick, which constantly protrudes the candle upwards against the wick in proportion as the tallow is consumed. His second method of constructing the candles is that of forming them in the usual shape, but with a perforation through their whole length; and the wick in this case is a small tuft of cotton, which is put into the opening at the top of the hollow candle, and to its lower part is attached a thread which passes down through the perforation to the bottom of the candle, where it penetrates the candlestick, and is wound round a key or pivot, and by turning this pivot, the wick that is attached to the upper part of the thread will be pulled down in proportion as the candle consumes. This method prevents the guttering of candles, as all the tallow that is melted is readily absorbed by the wick. By a small variation in the form of the candle, it may be made to serve the purpose of an Argand's lamp; for which end it is composed of a hollow cylinder of tallow, including another cylinder also perforated; and the wick, which is of a circular form, is here placed between the inner and outer cylinders. In all these cases, the wick is composed of thread, placed longitudinally, and not twisted, as is the case with the common wicks, which undoubtedly assists the capillary attraction of the melted tallow. These wicks have also the advantage of not requiring to be snuffed, for removing the carbonaceous matter which escapes unconsumed from the tallow. Another advantage attending these detached wicks, is the ease with which their bulk may be proportioned to that of the candle, and to the fusibility of the material of which it is composed. The patentee also proposes another improvement, which is that of subjecting the melted tallow or other material to a considerable pressure, during the act of cooling; which is done by means of a condensing machine, pressing the surface of the liquid substance, and then giving it a greater degree of firmness and solidity when cold. The patentee has likewise described, and illustrated by a drawing, the contrivance which he has adopted for casting the hollow cylindrical candles. For a detail of other circumstances that occur in his patent, we refer to his specification in the Repertory, vol. xii. p. 368.

CANDLES, laws relating to. Every maker of candles for sale, other than wax candles, shall take out an annual licence at 1l. 24 Geo. III. c. 41. 43 Geo. III. c. 69. And every person making wax or spermaceti candles shall take out a licence at 6l., and for dealing in, or selling such candles shall pay 10s. 6d., and renew the same annually, under a penalty of 20l. 24 Geo. III. c. 36. 43 Geo. III. c. 69. But no person who hath paid such licence duty for making, shall be obliged to take out a licence for selling also, during the same year. 24 Geo. III. c. 41. By 24 Geo. III. c. 74., no person, residing within the limits of the head-office, shall be permitted to make candles, unless he occupy a tenement of 10l. a year, assessed in his own name, and for which he pays the parish rates; and elsewhere, unless he be assessed and pay to church and poor. By 43 Geo. III. c. 69., in lieu of any subsisting duties of excise, the following duties are imposed; viz for every pound avoirdupois of candles, except those of

wax and spermaceti, made in Great Britain, 1d.; and for every pound of wax or spermaceti candles so made, 3½d. All places for making or keeping of candles, and of materials for the same, and furnaces, moulds, &c. for melting such materials, are forbidden to be used without notice previously given in writing at the next office of excise, under a penalty of 50l., and forfeiture of all candles and materials, furnaces, &c. which have not been entered. 8 Ann. c. 7. And by 11 Geo. c. 30., makers of candles who make use of such places or utensils without entry incur a forfeiture of 100l. Officers shall be permitted, at all times by day, and also in the night with a constable, to enter the house, melting-house, &c. of a maker of candles, and to take an account of the quantity, when all chests, &c. shall be opened; and the penalty of obstructing or molesting such officer is 100l.; or if candles, &c. be found in unentered places, the offender shall be convicted in the penalty of 100l. 11 Geo. c. 30.; see also 24 Geo. III. c. 11. and 27 Geo. III. c. 31. Any maker of candles shall give notice in writing to the proper officer of his intention to begin a course of dipping and preparing for the same, with a declaration of the time when he intends to commence his operation, and a specification of the number of sticks, moulds, &c. which he proposes to use, under a penalty of 50l. 13 Ann. c. 26. 11 Geo. c. 30. 24 Geo. III. c. 11. Such notice shall be given, within the limits of the head-office, 6 hours, within any city or market town, 12 hours, and elsewhere 24 hours, before he shall begin, on pain of forfeiting 50l. 25 Geo. III. c. 74. If he does not begin and proceed at the time mentioned, or within 3 hours next after, such notice shall be void. Having begun, he shall continue working without interruption, till the whole course is finished, on pain of forfeiting 50l. 26 Geo. III. c. 77. Every candle maker shall provide sufficient locks and fastenings to every furnace, copper, mould, &c. to be secured by the officer, when they are not used; and he shall give notice in writing to the said officer, 6 hours before the time when he wishes to use them, within the limits of the chief office, 12 hours in any market town, and 24 hours elsewhere; any offence against the provisions of this act incurs a penalty of 100l. 27 Geo. III. c. 31. The officer shall charge for materials that are missing, after he has taken account of the same; and obstruction incurs a forfeiture of 20l. Candles that are spoiled in making shall be defaced by the officer, and he shall make allowance for the duty. No maker of candles shall, on pain of 20l., remove candles before they are surveyed; and those that have not been surveyed are to be kept separate from the others, on pain of 5l. 8 Ann. c. 9. On suspicion, that candles are privately made, or concealed to evade the duty, the ground of which has been stated on oath before two commissioners or one justice residing near the place, the officer may be empowered by special warrant, granted by such justices or commissioners, to enter the place suspected, and to seize as forfeited all candles that are found, and all materials for making them; and the person so offending, or obstructing the officer, shall forfeit 100l. 5 Geo. III. c. 43. 23 Geo. II. c. 24. If any chandler shall mingle candles not weighed by the officer with those that have been weighed, or remove any before weighing, or conceal any candles or materials, he shall forfeit 100l. 11 Geo. c. 30. Any person who is found assisting in privately making candles shall forfeit 20l.; and every person making candles shall once in every week enter the same in writing at the next excise-office, with their weight, number, size, and quantity; on pain for every neglect of entry to forfeit 20l.; and in one week, after such entry, he shall clear off the duties, on pain of double duty, nor shall he carry out candles till the duty hath been paid, on pain of double value.

25 Geo. III. c. 74. Persons buying, receiving, or having in their possession candles, not charged with the duty, shall forfeit the same, and treble value. 26 Geo. III. c. 77. Nor shall any person expose to sale any candles, unless in his public shop or warehouse, public fair or market, on pain of 5l. 8 Ann. c. 9. No candles shall be imported, otherwise than in some package containing at least 224lb. of neat candles, on pain of being seized and forfeited, and the master of the vessel shall forfeit 50l. 23 Geo. II. c. 21. 42 Geo. III. c. 93. And no candles imported otherwise than according to 23 Geo. II. c. 21., shall be entered for exportation. 42 Geo. III. c. 93. All wax candles seized on importation or otherwise, and condemned for non-payment of the duties, shall be rendered unfit for use. 24 Geo. III. c. 36. Candles for which the duty hath been paid may be exported, with a draw-back of the duty. 8 Ann. c. 9. 43 Geo. III. c. 69. If any maker of candles shall obstruct any officer in the execution of the powers given him by any act for securing the duties on candles, he shall for every such offence forfeit 100l. 24 Geo. III. c. 11. Every maker shall keep just scales and weights, and permit and assist the officer in the use of them, on pain of 10l. 8 Ann. c. 9.; and if he use scales and weights that are insufficient, he shall forfeit 100l. 10 Geo. III. c. 44.; and by 28 Geo. III. c. 37, the same shall be forfeited, and may be seized by any officer of excise. Obstruction of the officer in weighing or the hindrance of his taking a just account of stock, subjects to a forfeiture of 100l. 26 Geo. III. c. 77.

CANDLES, Observations on the manufacture, comparative value, and use of different. The Roman candles were at first little strings dipped in pitch, or surrounded with wax; though afterwards they made them of the papyrus, covered likewise with wax; and sometimes also of rushes, by stripping off the outer rind, and only retaining the pith. For religious offices, wax candles were used; for vulgar uses, those of tallow. Serv. ad. Æn. l. i. v. 731. Plin. Nat. Hist. l. xvii. c. 37. Lord Bacon proposes candles of divers compositions and ingredients, and also of different sorts of wicks; with experiments on the degrees of duration, and light of each. Good housewives are said to bury their candles in flour, or bran, which, it is said, increases their durability, almost one half. Some speak of perpetual candles made of Salamander wood. Bac. Nat. Hist. Cent. 4. c. 369. and Cent. 8. c. 744.

The two substances most commonly used in the manufacture of candles are wax and tallow. Wax owes its whiteness, and the greater consistency it acquires, to an absorption of the vital part of the atmosphere; and in this circumstance it seems principally to differ from tallow, or concrete oil. But as wax is already combined with a portion of vital air or oxygene, it does not burn with so luminous a flame as tallow or oil. But it possesses a very great advantage in the fabrication of candles, arising from its freezing point being placed at a considerably higher temperature than that of the other substance. Tallow melts at the 92d. degree of Fahrenheit's thermometer; spermaceti at the 133d. degree; and bleached wax at 155°. Hence it will not be difficult to explain the chief advantage of wax candles compared with those of tallow. Oils, it should be considered, do not take fire, unless they be previously volatilized by heat; and this is effected by means of the wick of a candle, or lamp. The oil rises between the fibres of the wick by the capillary attraction. Heat, being applied to the extremity of the wick, volatilizes and sets fire to a portion of the oil. While this is dissipated by combustion, another portion passes along the fibres, or supplies its place by becoming heated and burned likewise. In this way a constant combustion is maintained. A candle, how-

ever, differs from a lamp in one very essential circumstance; viz. that the oil, or tallow, is liquefied only as it comes to be in the vicinity of the conflagration; and this fluid is retained in the hollow of the part, which is still concrete, and forms a kind of cup. The wick, therefore, should not, on this account, be too thin; because if this were the case, it would not carry off the fluid as fast as it becomes fused; and the consequence would be, that it would run down the sides of the candle; and as this inconvenience arises from the fusibility of the oil, it is plain that a more fusible candle will require a larger wick; or that the wick of a wax candle may be made thinner than that of one of tallow. The flame of a tallow candle will of course be yellow, smoky, and obscure, except for a short time after snuffing. When a candle with a thick wick is first lighted, and the wick snuffed short, the flame is perfect and luminous, unless its diameter be very great; in which last case, there is an opaque part in the middle, where the combustion is impeded for want of air. As the wick becomes longer, the interval between its upper extremity, and the apex of the flame is diminished; and consequently the oil, which issues from that extremity, having a less space of ignition to pass through, is less completely burned, and passes off partly in smoke. This evil increases, until at length the upper extremity of the wick projects beyond the flame and forms a support for an accumulation of soot which is afforded by the imperfect combustion, and which retains its figure, until, by the descent of the flame, the external air can have access to the upper extremity. But in this case, the requisite combustion which might snuff it, is not effected; for the portion of oil emitted by the long wick is not only too large to be perfectly burned, but also carries off much of the heat of the flame, while it assumes the elastic state. By this diminished combustion, and increased efflux of half-decomposed oil, a portion of coal or soot is deposited on the upper part of the wick, which gradually accumulates, and at length assumes the appearance of a fungus. The candle does not then give more than one-tenth of the light which the due combustion of its materials would produce; and, on this account, tallow candles require continual snuffing. But if we direct our attention to a wax candle, we find that as its wick lengthens, the light indeed becomes less. The wick, however, being thin and flexible, does not long occupy its place in the centre of the flame; neither does it, even in that situation, enlarge the diameter of the flame, so as to prevent the access of air to its internal part. When its length is too great for the vertical position, it bends on one side; and its extremity, coming in contact with air, is burned to ashes; excepting such a portion as is defended by the continual afflux of melted wax, which is volatilized, and completely burned, by the surrounding flame. Hence it appears, that the difficult fusibility of wax renders it practicable to burn a large quantity of fluid by means of a small wick; and that this small wick, by turning on one side in consequence of its flexibility, performs the operation of snuffing upon itself, in a much more accurate manner than it can ever be performed mechanically. From the above statement it appears, that the important object to society of rendering tallow candles equal to those of wax, does not at all depend on the combustibility of the respective materials, but upon a mechanical advantage in the cup, which is afforded by the inferior degree of fusibility in the wax: and that, in order to obtain this valuable object, one of the following effects must be produced: either the tallow must be burned in a lamp, to avoid the gradual progression of the flame along the wick; or some means must be devised to enable the candle to snuff itself, as the wax-candle does; or the tallow itself must be rendered less fusible by some chemical process. With a

view to the first of these objects, a cylindrical piece of tallow was inserted into a metallic tube, the upper aperture of which was partly closed by a ring, and the central part occupied by a metallic piece nearly resembling that part of the common lamp which carries the wick. This piece was provided with a short wick. The cylinder of tallow was supported beneath in such a manner that the metallic tube and other part of this lamp were left to rest with their whole weight upon the tallow at the ring or contraction of the upper aperture. In this situation the lamp was lighted, and it burned for a considerable time with a bright clear flame, more uniformly intense than that of a candle, and superior to the ordinary flame of a lamp in its colour and the perfect absence of smell. After some minutes it began to decay, and soon afterwards went out. Upon examination it was found, that the metallic piece which covered the wick had fused a sufficient quantity of tallow for the supply during the combustion; that part of this tallow had flowed beneath the ring, and to other remote parts of the apparatus, beyond the influence of the flame; in consequence of which, the tube and the cylinder of tallow were fastened together, and the expected progression of supply prevented. In every lamp for burning consistent oils, it seems probable, says Mr. Nicholson (*ubi infra*), that the materials ought to be so disposed as to descend to the flame upon the principle of the fountain reservoir. Although this construction failed, a contrivance of a similar nature would be of very great public utility. With regard to the second object above specified, Mr. Nicholson is led by various considerations to imagine, that the spontaneous snuffing of candles made of tallow or other fusible materials, will scarcely be effected but by the discovery of some material for the wick, which shall be voluminous enough to absorb the tallow, and at the same time sufficiently flexible to bend on one side. The most promising speculation respecting this most useful article, seems to regard the cup which contains the melted tallow. This is apt to break down by fusion, and thus to suffer its fluid contents to escape. The Chinese have a kind of candle about half an inch in diameter, which, in the harbour of Canton, is called a "lobchock." The wick is of cotton, wrapped round a small stick or match of the bamboo cane. The body of the candle is white tallow; but the external part to the thickness of about one thirtieth of an inch consists of a waxy matter coloured red; this covering gives a considerable degree of solidity to the candle and prevents its guttering, because it is less fusible than the tallow itself. The stick in the middle might probably be of advantage in throwing up a less quantity of oil into the flame than would have been conveyed by a wick of cotton sufficiently stout to have occupied its place unsupported in the axis of the candle. Mr. Nicholson says that he formerly made a candle in imitation of the "lobchock." For this purpose he adapted the wick in the usual pewter mould; he then poured in wax, which was immediately afterwards poured out; the film of wax, adhering to the inner surface of the mould, soon became cool; and the candle was completed by filling the mould with tallow. When it was drawn out, it was found to be cracked longitudinally on its surface, which he attributed to the contraction of the wax, by cooling, being greater than that of the tallow: or it might have been owing to the too sudden cooling of the wax before the tallow was poured in. The experiment was not repeated. After all, the most decisive remedy for the imperfection of this cheapest, and in other respects best material for candles, would undoubtedly be a diminution of its fusibility: with this view Mr. Nicholson made some experiments. The object is, in a commercial view, entitled to assiduous and extensive investigation. Chemists in general, suppose the hardness or less fusibility of wax to arise from

oxygen; and to this object attention should be directed in the inquiry. Nicholson's First Principles of Chemistry, p. 517. Nicholson's Journal, Vol. I. p. 70.

The Chinese obtain from the tallow tree (*Croton sebiferum*, Linn.) a kind of vegetable fat, with which they make a considerable proportion of their candles; which are firmer than those of tallow, and free from all offensive odour; but they are not equal to those of wax, or spermaceti. Cheap candles are also made of tallow, and even of grease of too little consistence to be used, without the contrivance of being coated with the firmer substance of the tallow tree or of wax. The surface of these candles is sometimes painted red. Their wicks are made of different materials. For their lamps, they use the amianthus, which burns without being consumable in fire, or the artemisia, and carduus marianus, with which tinder is also made; but for candles, they use a light inflammable wood, in the lower extremity of which is pierced a small tube to receive an iron pin, which is fixed on the flat top of the candlestick, and thus supports the candle, without the necessity of a socket. The candle-makers at Munich have for several years past prepared tallow candles with wooden wicks, which afford about the same quantity of light as a wax candle, burn also with great steadiness and uniformity, and never crack or run. These wicks are formed of very thin slips of wood, bound round to a considerable thickness with very fine unspun cotton, but such that the size of the wick does not much exceed that of the wick of a common candle. The candle-makers either purchase or prepare for themselves these slips of wood, which are somewhat square and not completely rounded, and are made of pine, willow, and other kinds of wood, but most commonly of fir. Some take shoots of the pine-tree a year old, or common fir twigs of the same age, scrape off the bark, and reduce them to the size of a small straw; they then rub over these rods with wax or tallow, till they are covered with a thin coating of either of these substances; after which they roll them on a smooth table in a very fine carded cotton, drawn out to about the length of the rod or candle-mould. After this preparation the wick will have acquired the size of the barrel of a small quill; and the more accurately the size of the wick is adapted to that of the candle-mould, so much the clearer and longer will the candle burn. These wicks are then placed very exactly in the middle of the mould, and retained in that position; and good fresh tallow, previously melted with a little water, is then poured round them; but old and rancid tallow will not run if the wicks be properly made. These candles not only burn longer than the common ones, but they do not flare, and they are less prejudicial to the eyes of those who are accustomed to read or write at night. They must be snuffed with a pair of sharp

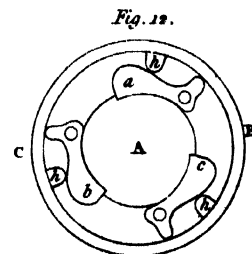
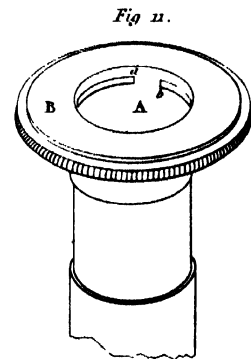
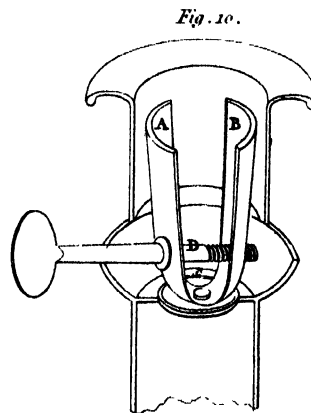
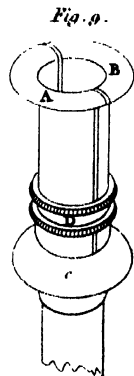
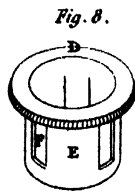
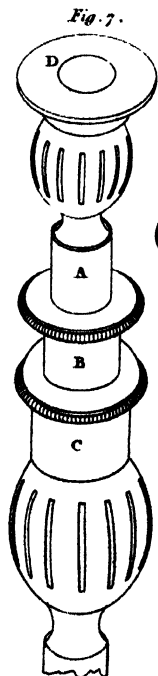
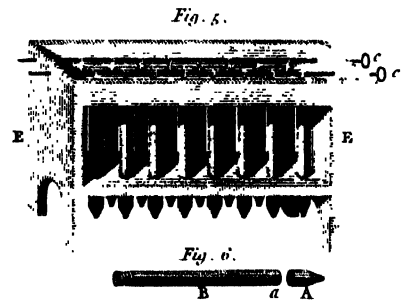
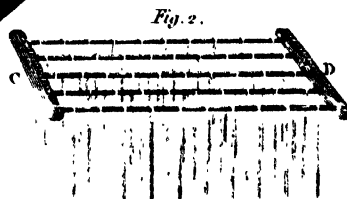
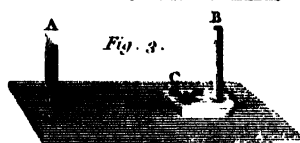
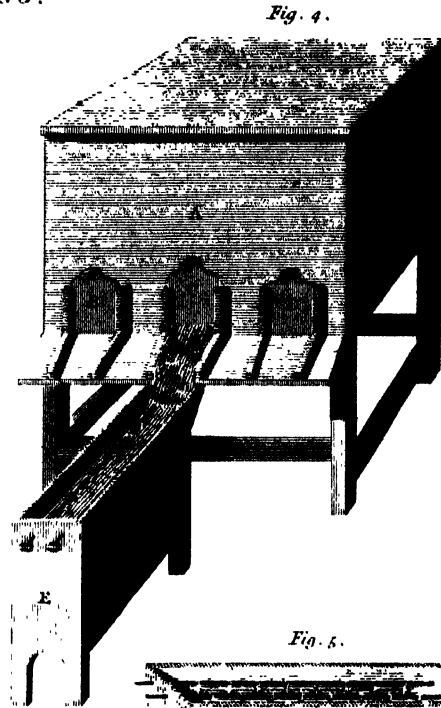
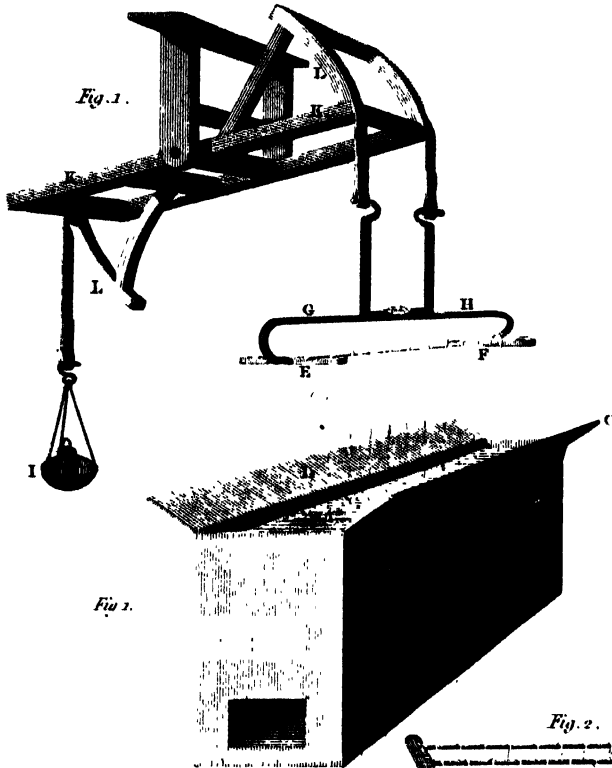
scissors, and in doing this care must be taken not to damage or break the wick.

It has been suggested by Dr. Franklin, that the flame of two candles joined gives a much stronger light than both of them separate. Probably the union of the two flames produces a greater degree of heat, by which the vapour is attenuated, and the particles of which light consists more copiously emitted. Priestley's Hist. of Vision, &c. p. 807. For a comparison of the light of a candle with that of a lamp, see LAMP. For the method of estimating the intensity of candle-light, &c. see LIGHT and PHOTOMETRY.

Dr. Ingenhouz has described in the Philosophical Transactions (vol. 68.) a method of lighting a candle by a small electrical spark. For this purpose he uses a small phial, having 8 or 10 inches of metallic coating, or even less, charged with electricity; and the operation may be performed at any time of the night by a person, who has an electrical machine in his room. "When I have occasion to light a candle," says he, "I charge a small coated phial, whose knob is bent outwards, so as to hang a little over the body of the phial; then I wrap some loose cotton over the extremity of a long brass pin or a wire, so as to stick moderately fast to its substance. I next roll this extremity of the pin wrapped up with cotton in some fine powder of resin, which I always keep in readiness upon the table for this purpose, either in a wide-mouthed phial or in a loose paper; this being done, I apply the extremity of the pin or wire to the external coating of the charged phial, and bring as quickly as possible the other extremity wrapped round with cotton to the knob; the powder of resin takes fire and communicates its flame to the cotton, and both together burn long enough to light a candle. As I do not want more than half a minute to light my candle in this way, I find it a readier method than kindling it by a flint and steel, or calling a servant. I have found, that powder of white or yellow resin lights easier than that of brown. The "farina lycopodii" may be used for the same purpose; but it is not so good as the powder of resin, because it does not take fire quite so readily, requiring a stronger spark not to miss; besides, it is soon burnt away. By dipping the cotton in oil of turpentine, the same effect may be as readily obtained, if you take a jar somewhat greater in size. This oil will inflame so much the readier if you strew a few fine particles of brass upon it. The pin dust is the best for this purpose; but as this oil is scattered about by the explosion, and when kindled fills the room with much more smoke than the powder of resin, I prefer the last."

For the method of lighting candles by phosphoric tapers or matches, see PHOSPHORUS.

CANDLE. CANDLE MAKING.



CANDLESTICKS.

Carbon

CARBON, in *Chemistry*.

§ 1. *Of Carbon.*

This substance abounds largely in all vegetable and animal bodies, as well as in the mineral kingdom, yet it is of very rare occurrence in a state of absolute purity. When uncombined with any foreign matter, it is transparent, colourless, intensely hard, and crystallized; and, both on account of its beauty and value, is placed at the head of the gems under its commercial and mineralogical name **DIAMOND**.

Diamond was formerly supposed to be incombustible, and the first hint at its real nature was given by Newton. This philosopher having observed that inflammable bodies possess, in proportion to their density, a greater power of refracting the rays of light than any other substances, was induced to rank the diamond among them, on account of the eminent degree in which it possessed this property. This conjecture was verified, in 1691, by the members of the Academy del Cimento at Florence, who consumed several diamonds by placing them in the focus of a lens. Francis I. emperor of Germany, afterwards witnessed the destruction of several more by the heat of a furnace. These experiments were repeated by Macquer, Rouelle, Darcet, and Cadet, who ascertained, that by the concurring action of air and heat, diamond was not only evaporated, but actually burnt with flame; they also proved that when the air was excluded the highest heat of a furnace produced little or no effect on this substance.

In 1772, an experiment was made by Lavoisier, which may be considered as the first attempt to effect a chemical analysis of diamond. He burnt a few grains of this substance in a jar of common air, confined over mercury, by means of a very powerful lens, and found that the pure part

of the air had disappeared, as well as a considerable proportion of the diamond, and that the residual air abounded with carbonic acid: repeating the same process only with the substitution of an equal weight of highly burnt charcoal, he found precisely analogous effects to take place, and therefore concluded that diamond and charcoal in their chemical essence were very similar to each other. In 1785, M. Morveau discovered that diamond, when dropped into melted nitre, burns like charcoal, and without leaving any residuum. This fact suggested to Mr. Tennant a method of analysing diamond, which was effected with complete success. Into a gold tube, closed at one end, and terminating at the other in a curved glass tube, were put a quarter of an ounce of nitre and $2\frac{1}{2}$ grains of diamonds; the tube was then kept at a full red heat for an hour and a half, and when its contents were afterwards examined, the diamonds were found to have entirely disappeared, and the nitre was changed into sub-carbonat of potash; to a solution of this salt muriat of lime was added, and thus the carbonic acid was transferred to the lime: from this carbonat of lime the carbonic acid was expelled by means of the muriatic acid, and was found to amount to 9.03 grains. Hence 27.6 parts of diamond and 72.4 of oxygen constitute 100 of carbonic acid. But, according to Lavoisier, 28 parts of charcoal, and 72 of oxygen constitute 100 of carbonic acid; therefore diamond and pure charcoal may be considered as chemically the same.

Morveau has since endeavoured to invalidate the experiment of Mr. Tennant, and to shew that diamond is pure carbon and that charcoal is an oxyd of carbon, but his experiment is so manifestly incorrect as to merit no sort of confidence.

A further proof of the analogy between charcoal and diamond is furnished by an ingenious experiment of Clouet's, in which

which some pure bar iron being exposed to a high heat, in contact with diamond, this latter substance was found to have disappeared, and the iron to be converted into steel.

But though diamond is the purest form of carbon, yet its high value, its hardness, and density, forbid it to be used in ordinary chemical experiments; all the succeeding facts, therefore, relate to that less pure kind of carbon which is obtained by exposing common CHARCOAL, or, still better, lamp-black, to a high heat in close vessels.

Carbon, or prepared charcoal, is an excellent conductor of galvanism and electricity, but transmits caloric with very great difficulty; a short piece may be held by one end while it is heated red at the other, without conveying any notable warmth to the hand.

It is insoluble in water, and even the combined action of air and water produces hardly any perceptible effect upon it; hence it is that stakes of wood that are charred on the outside will last much longer without rotting than the soundest timber that has not undergone this preparation.

Charcoal is not fusible by the greatest heat that can be applied: if exposed to a very high temperature in close vessels it loses little or nothing of its weight, but shrinks in size, and becomes proportionably more compact, dense, and sonorous, and acquires a deep velvet black colour. But though charcoal is unalterable by mere heat, yet when heated red in the open air, it speedily undergoes combustion, and is converted into CARBONIC ACID; pure oxygen gas produces, as might be expected, a much more powerful effect on this substance than atmospheric air does; a piece of charcoal barely heated at one end to redness and plunged into this gas, immediately burns with an intensely white glow, and is rapidly changed into carbonic acid.

Water, although it is, as we have already mentioned, incapable of dissolving carbon, is yet very obliquately retained by it, partly on account of its porous texture, and in part probably on account of a strong mutual affinity subsisting between them. When, however, charcoal is red hot, or nearly so, it decomposes any water with which it may happen to be in contact, and unites with both the elements of this substance; producing with the oxygenous base, according as this is added to saturation or not, carbonic acid and carbonous oxyd; and with the hydrogenous base forming a heavy inflammable air, called carburetted hydrogen or hydrocarbonat.

Newly prepared charcoal is capable of absorbing various gasses, with remarkable facility, and in considerable proportions. This fact had been observed by Fontana, Lavoisier, Priestley, Scheele, and Morveau, but the first important series of experiments on this subject was published by Morozzo, since which time Messrs. Rouppe and Van Noorden of Rotterdam have made a considerable and very valuable addition of facts on this curious subject. The charcoal for the experiment being highly ignited in an open fire, to expel all the moisture and gaseous substances which it may contain, is quickly removed, and extinguished by being plunged under mercury, or inclosed in an air-tight metallic box; when quite cool it produces the following effect on the various gasses.

One part of charcoal is capable of absorbing three times its bulk of atmospheric air in four or five hours; of oxygen gas there is absorbed, at first rapidly, and afterwards more slowly, 2.8 times the bulk of the charcoal. Azot and hydrogen are taken up instantaneously, but only in the proportion of 1.6 of the former, and 1.8 of the latter. Of nitrous gas 8.5 parts are very slowly, and of carbonic acid 14.3 parts are very rapidly absorbed. The gasses thus taken up undergo no change except of form, nor are the residues

at all altered, and they may be all again separated from the charcoal by distillation, at the temperature of boiling water. If charcoal saturated with hydrogen in the way described is introduced into oxygen gas, or even into atmospheric air, a considerable absorption of the oxygen takes place, and combines with the hydrogen, forming water, and at the same time the temperature rises to about 100° Fahr. The result is the same if the experiment is inverted, that is, if charcoal charged with oxygen is introduced into hydrogen gas. Charcoal saturated with hydrogen is even capable of decomposing nitrous gas, the oxygen being absorbed and the azot alone remaining in the elastic state. Charcoal saturated with azot is also capable of decomposing atmospheric air, by abstracting the oxygenous part, which is a remarkable proof how adverse the gaseous state is to chemical combination.

Carbon is capable of combining with sulphur; the substance hence resulting is called carburetted sulphur, and almost all that is known as yet concerning it is due to the united investigations of Clement and Desormes, two French chemists. It is thus prepared. Fill an earthenware tube with small pieces and powder of newly burnt charcoal, fix it in a slanting direction in a furnace, and lute to the lower end a glass tube, dipping it into some water contained in a receiver. Fasten a glass tube also to the upper extremity of the earthen pipe, and fill it with short cylindrical pieces of sulphur, and fit a cork to the open end of the glass tube with a moveable wire passing through its centre, by which the pieces of sulphur may be pushed at pleasure towards the earthen pipe. The apparatus being completed, heat the pipe very gradually, and as soon as the gas casually contained in the charcoal is driven out, cause the sulphur, by means of the wire, to approach the heated part of the apparatus. Allow it to remain at such a distance that it may melt as slowly as possible, and run down among the charcoal; and if these precautions are duly observed, a yellowish oily liquor will soon be perceived in the terminating glass tube, which will drop into the water of the receiver, and collect at the bottom of the vessel, without at all uniting with the supernatant fluid. The carburet of sulphur thus obtained is a transparent liquid, colourless when pure, but generally of a yellowish-green tinge, and of a disagreeable slightly pungent odour, differing, entirely, however, from that of sulphuretted hydrogen. The specific gravity of carburetted sulphur is about 1.3. It evaporates in the air with nearly the same rapidity as ether, and, like this fluid, sinks the thermometer during the process in a remarkable degree. If it is put into an air-pump, and the atmospheric pressure be reduced to about nine inches of mercury, the carburetted sulphur begins to assume the form of a gas; but upon restoring the common pressure, this gas will immediately again resume its liquid state. It takes fire upon the application of a flame, and burns like alcohol, giving out at the same time a sulphurous odour, and depositing both sulphur and carbon. When kept for some time in a vial with atmospheric or azotic gasses, it is dissolved by them in small proportion, and renders them inflammable. It combines with nitrous gas, and the mixture burns like zinc. When dissolved in oxygen gas, the result is an air that explodes with such prodigious violence as to render it dangerous to set fire to even a few ounce measures at the same time. In the state of vapour it combines slowly with the caustic fixed alkalis, forming with them deep amber-coloured solutions. By alcohol it is reduced to a soft pasty consistence. It dissolves very easily in cold olive oil, or in ether, deposits a little charcoal, and then assumes a crystalline form.

Carbon is said by Proust to be capable of uniting with

phosphorus, but this, from subsequent experiments, appears to be a mistake.

Two of the metals are known to unite with charcoal; when combined with Iron the product is called steel; and with COPPER it forms a peculiar substance, first noticed by Dr. Priestley, and named by him charcoal of copper.

The action of the alkalis upon charcoal has been but little examined into; it is certain, however, that caustic potash, by long digestion with this substance, becomes coloured and partly carbonated.

The undecomposable acids appear to have no action on charcoal, but the decomposable ones are deprived by it of their oxygen, either entirely or in part, and the charcoal is changed into carbonic acid; thus phosphoric acid and charcoal yield, by ignition, phosphorus and carbonic acid; sulphuric acid and charcoal yield sulphur, sulphureous acid, and carbonic acid. If highly dried and finely pulverised charcoal is poured into recently prepared oxymuriatic acid gas; as soon as the two substances come into contact the charcoal becomes red hot, and falls to the bottom of the vessel, like a shower of fire.

The neutral and earthy salts with decomposable acids are remarkably changed at a red heat by charcoal: the others suffer no perceptible alteration. Thus the sulphates are converted into sulphurets, the nitrates become carbonates, while the muriates and fluats remain unchanged.

The metallic salts are all of them decomposed by charcoal at a greater or less degree of heat, in consequence of the deoxygenation of their bases, independently of the action of this substance on their acids.

The effects of charcoal in clarification are both curious and important. They were first noticed by M. Lowitz of Petersburg, and have for the most part been amply confirmed by succeeding observers, although the precise cause of these remarkable changes has not been satisfactorily ascertained. All that is essential for this purpose is, that the charcoal should be in fine powder and very dry; hence the only preparation requisite is to pulverize some well burnt common charcoal, and then heat it in a covered crucible to a glowing red, till it ceases to give out an inflammable vapour. If it is not employed immediately, it ought to be kept in a ground stoppered glass bottle, and may then be preserved unimpaired for any length of time. The effects of this prepared charcoal are very striking. Being mixed with common vinegar, or any kind of wine, a thick froth rises to the surface, and the liquors, after filtration, are found to be as limpid as water. The filthiest and most putrid ditch-water is in like manner rendered perfectly clear, inodorous and insipid; and rancid oils are also deprived of their smell and taste by repeated filtration through this prepared charcoal. Hence also its peculiar efficacy as a dentrifice; it is sufficiently hard to remove the concretions from the teeth without injuring the enamel, while it neutralizes and entirely destroys for a time any sceler which may arise from a carious tooth.

§ 2. Of carbonous oxyd, or gaseous oxyd of carbon.

Dr. Priestley was the first person who effectually called the attention of chemists to this substance; but for a correct acquaintance with its nature and properties we are indebted to Mr. Cruickshank. It had always been objected by Dr. Priestley, against Lavoisier's hypothesis of the constitution of fixed air, that when charcoal, however dry, was distilled with scales of iron, or the red oxyd of mercury, the product was not only carbonic acid, but a large quantity of a heavy, inflammable air, resembling, in many respects, carburetted hydrogen, and supposed by Dr. Priestley to be actually this very gas. Now carburetted hydrogen consists of hydrogen, holding carbon in solution; and if it were really produced

by the mutual action of carbon and a metallic oxyd, could only be accounted for upon the Lavoisierian theory by the casual presence of some water. But the gas is produced in such great abundance, even when the materials have separately been first exposed to a very high heat to drive off every atom of water, that this hypothesis is untenable; it is, therefore, an obligation of no trifling kind that the modern chemical theory is under to Mr. Cruickshank, for having shewn that this gas, though inflammable, does not necessarily contain any hydrogen whatever, but has only a simple combustible base, namely, carbon, and differs from carbonic acid merely by its smaller proportion of oxygen. Hence, it is properly called an oxyd of carbon, and bears the same analogy to carbonic acid as the nitrous oxyd does to the nitric acid. The experiments of Mr. Cruickshank have been repeated with much apparent accuracy by Messrs. Clement and Deformes, and the results obtained by them correspond very nearly with those of the former chemist.

The gaseous oxyd of carbon may be produced either by the partial oxygenation of carbon, or the partial deoxygenation of carbonic acid, or the solution of carbon in carbonic acid, on each of which methods we shall proceed to say a few words.

The original experiment by Dr. Priestley is the following. Equal parts of scales of iron and charcoal (each having previously been ignited in separate vessels), were put into a glazed earthen retort and strongly heated. In a short time a prodigious quantity of air came over, which, on examination, was found to consist of one tenth carbonic acid, and the remainder was "an inflammable air of a very remarkable kind, being quite as heavy as common air. The reason of this," Dr. Priestley adds, "was very apparent, when it was decomposed by dephlogisticated air, for the greater part of it was fixed air." The above two important properties, namely, the weight of this gas and its almost total convertibility into carbonic acid by oxygen, are fully confirmed by subsequent experiments.

Mr. Cruickshank, in repeating this experiment of Dr. Priestley, found, that as soon as the retort was red, abundance of gas came over, which, being examined at different periods, was found, in the beginning of the process, to be composed of one part of carbonic acid and four of carbonous oxyd, with a small admixture of carburetted hydrogen; after this, to the end of the process, the proportion of carbonous oxyd gradually increased to about six-sevenths of the whole. Two ounces of the materials afforded many gallons of the gas.

The sublimed oxyd of zinc was next substituted to the iron scales, and distilled in the same manner with charcoal. Even before the retort became red much gas was given out, and, on increasing the heat, it came over in torrents. It contained a much smaller proportion of carbonic acid than the former, and, towards the end, consisted of pure oxyd of carbon. Part of the zinc was found, in the metallic state, sublimed into the neck of the retort. In like manner litharge, the grey oxyd of manganese, and the red oxyd of copper, produced with charcoal, first, a mixture of carbonic acid with carbonous oxyd, and, at last, the inflammable gas in a state of purity.

The distillation of charcoal and the sublimed oxyd of zinc was repeated by Clement and Deformes, with particular attention to the quantity of products from a given weight of materials. The charcoal and zinc were first heated separately, and examined. Common charcoal, when heated strongly, gave a considerable quantity of inflammable gas, and about $\frac{1}{4}$ th of its weight of water. After an hour nothing further came over; so that, to ensure the purity of

the charcoal, it should be used hot from the crucible or other vessel in which it has been exposed to a full red heat for half an hour. The oxyd of zinc gave out nothing at all by being heated *per se*; so that it may at any time be considered as pure, when previously free from accidental moisture.

It was found, by experiment, that 14.36 parts of zinc increased, by calcination, to 17.48 of white sublimed oxyd; and hence it is inferred that 100 parts of white oxyd consist of 82.15 metal, and 17.85 oxygen. Pure charcoal, prepared as above, was mixed, to the amount of 30 grammes, (463 grains) with an equal weight of oxyd of zinc, which were put into a coated glass retort, communicating with lime-water, through which all the gaseous products passed. When first heated, a small portion of carbonic acid gas appeared, rendering the lime-water turbid; but this soon ceased, and the gas was purely inflammable. In five hours the production of gas had entirely terminated, and the total products of the operation were as follows:

	Grammes.
Zinc sublimed in the retort	21.82
Charcoal remaining -	26.60
Carbonic acid	0.07
Nine litres (16.9 wine pints) of inflammable gas	10.35
	58.84
Loss	1.16
	<hr/> 60.00

In all the preceding experiments the carbonous oxyd was obtained by the partial deoxygenation of the metallic oxyds and the consequent oxygenation of the carbon. In those which we are about to relate, the same gas was procured by inverting the process, that is, by depriving carbonic acid of a portion of its oxygen.

Dr. Priestley, having obtained an inflammable gas, by heating together carbonat of barytes and magnetic oxyd of iron, Mr. Cruickshank was induced to vary the experiment in the following manner. Equal parts of chalk (heated red hot previously for ten minutes), and of iron filings were mixed together, and heated in an earthen retort, abundance of gas was given out, consisting pretty uniformly of one part carbonic acid and five of carbonous oxyd.

An ounce of chalk previously heated red for ten minutes, was mixed with an equal weight of zinc filings, and heated gradually in a coated glass retort. A little carbonic acid came over at first, but mixed with oxyd of carbon; and when the contents of the retort were thoroughly red, nothing but the inflammable gas came over, and that in prodigious quantity. It was examined at different periods of the distillation, and proved to be wholly unmixed with carbonic acid. After the process, the retort being examined, there was found some sublimed oxyd of zinc in its neck, below which was some metallic zinc, and at the bottom was a mixture of oxyd of zinc, and partly caustic lime. Chalk, with tin filings, gave a similar result.

In these experiments, the carbonic acid was united to an earthy base before distillation, and consequently was exposed to the deoxygenating effect of the metallic filings in its nascent state, or, at the moment of its assuming the gaseous form, a state in which airs of all kinds are peculiarly susceptible of chemical change. Mr. Cruickshank found, however, that carbonic acid, even in the elastic state, was also susceptible of being deoxygenated by the same means, though not quite so easily. For this purpose, some dry chalk was in-

troduced into an iron retort, over which was rammed some dry sand, and a stratum of iron-filings over all. In this arrangement, the carbonic acid gas expelled from the chalk had to traverse a stratum of sand three inches thick, before it could reach the iron-filings. The gaseous products of the distillation were a quantity of undecomposed carbonic acid, together with a large proportion of the inflammable gas, and the iron-filings were taken out considerably oxygenated. The decomposition of carbonic acid by metals does therefore take place, when the acid is in the gaseous form, but by no means so perfectly as when in its nascent state. A similar decomposition was also effected by forcing the same carbonic acid gas successively backwards and forwards through an iron tube, the middle of which was full of iron-filings, and kept red hot by a small furnace placed beneath it. A bladder was tied to each end of the tube to receive the gas, and, by passing it twenty times slowly through the tube, two thirds of it were converted into inflammable gas.

It is obvious, that if to any base, already united with oxygen, we add a fresh portion of the base, it will have the same relative effect as abstracting part of the oxygen; and this offers another mode of preparing carbonous oxyd, which has been successfully practised by Messrs. Clement and Desormes. Pelletier had previously discovered that though the native carbonat of barytes is scarcely calcinable, *per se*, in any fire, yet it will readily part with its acid by calcination, if previously ground to fine powder, and mixed with a little charcoal. The chemists above-mentioned, on repeating this experiment with three parts of carbonated barytes and one of charcoal, obtained a large quantity of gas, composed of about $\frac{1}{2}$ carbonous oxyd, and $\frac{1}{2}$ carbonic acid, and the barytes remaining in the retort was found to be quite caustic. Here, therefore, it is to be supposed, that the carbonic acid is super-saturated with its own base, and thus rendered much more volatile than before.

A more direct combination of carbon with carbonic acid was also obtained by the two associated chemists just mentioned, with precisely the same apparatus as that used by Mr. Cruickshank for passing carbonic acid gas over red hot iron, except that the tube was filled with pulverized charcoal instead of iron-filings. The first sensible effect produced on the gas was a considerable dilatation, exclusive of the mere expansion by heat, and arising from the solution of a part of the heated charcoal in the gas as it passed over. After each experiment, by far the greater part of the carbonic acid was changed into the inflammable gaseous oxyd of carbon, the residual carbonic acid not amounting to more than from $\frac{1}{75}$ th to $\frac{1}{35}$ th of the whole. The remaining charcoal being taken out and weighed was found to be considerably diminished; but the proportional loss was uniformly greater in tubes of iron, than of glass or porcelain, doubtless on account of part of the carbon being combined with the iron, and thus converting it internally into steel. The composition of the gaseous oxyd, into which the carbonic acid was changed, calculated from the amount of charcoal taken up by it in porcelain tubes, appears to be about $\frac{5}{3}$ of oxygen, and $\frac{4}{7}$ of carbon.

The properties of pure carbonous oxyd, prepared from chalk or carbonat of barytes, and filings of iron or zinc, are the following. It is lighter than atmospheric air, in the proportion of 22 to 23. Hence, its specific gravity (that of water being 1000), will be 1.177, while that of atmospheric air is 1.2308; hence, it materially differs from carburetted hydrogen, the weight of which is not more than half that of common air. It suddenly destroys animal life.

It is in no degree altered by being electrized, *per se*, for a considerable length of time. It burns in the open air with a quiet, blue flame. When previously mixed with common air and kindled, it does not explode but burns slowly: when mixed with oxygen gas, and fired by the electric spark it explodes, but not very violently, and gives out a red flame. If a small jet, communicating with a reservoir of this gas, be set fire to, and introduced into a large balloon receiver filled with oxygen gas, it is found to burn brightly for a time, and afterwards goes out. The gas remaining in the receiver is not greatly diminished, and the inside of the vessel, though somewhat damp, is by no means studded with those visible drops of liquid that characterize the combustion of hydrogen. The residual gas, on examination, will be found to consist of carbonic acid with some uncombined oxygen.

The relative proportions of carbonous oxyd and oxygen requisite to mutual saturation, and the consequent production of carbonic acid, are the means of ascertaining the exact constituent parts of this inflammable gas. When 20 measures of pure gaseous oxyd are mixed with eight measures of oxygen and exploded, the whole is reduced to 18 or 19 measures, and is entirely absorbable by lime-water; it is, therefore, carbonic acid. The weight also of this latter product is found to correspond, as nearly as can be expected in experiments of this kind, with the sum of the weight of its two ingredients before mixture. One hundred cubic inches of carbonous oxyd with 40 inches of oxygen produce 92 cubic inches of carbonic acid, and the weight of the first may be estimated at 30 grains, of the second at 13.6, and of the third at 43.2; the sum of the two first differing from the third only by 0.4 of a grain.

Hence it may be inferred, that 100 parts, by measure, of gaseous oxyd of carbon, require for saturation 40 measures of oxygen gas, and produce, by combustion, about 92 measures of carbonic acid gas; or, by weight, that 100 grains of carbonous oxyd require about 45.5 grains of oxygen, and are converted into 144 grains of carbonic acid, 1.5 grain being allowed for water and casual impurities. Now carbonic acid has been found by Lavoisier and other chemists to consist of 28 parts, by weight of carbon, and 72 of oxygen; consequently 144 grains of carbonic acid (the product of the full oxygenation of 100 grains of the inflammable gas), contain 40.32 grains of carbon; therefore the remainder of the 100 grains of the oxyd, i. e. 59.68 grains, must be oxygen. Hence, carbonous oxyd may be stated as composed of

40.32 carbon
59.68 oxygen
100.00

Or, by another calculation, 144 grains of carbonic acid contain 72 per cent., or 103.68 grains of oxygen; but only 45.33 grains of oxygen were added to the inflammable gas to produce this carbonic acid, and, consequently, the difference between 103.68 and 45.33, or 58.35 grains of oxygen were already contained in the gas, leaving 41.65 grains, to complete the 100 grains of this gas, for carbon: hence, according to this calculation, carbonous oxyd consists of

41.65 carbon
58.35 oxygen
100.00

We may, therefore, reckon on an average, that 100 grains

of carbonous oxyd, obtained from the decomposition of the earthy carbonates by metallic substances in its purest possible state, unmixed with any hydrogen, are composed of about 41 of carbon and 59 of oxygen.

A true combustion of the gaseous oxyd of carbon takes place when it is mixed with oxymuriatic acid gas. If the latter be recently made and added to carbonous oxyd in due proportion, the whole mixture is converted into carbonic acid and simple muriatic acid; the carbonous oxyd having been fully oxygenated by the excess of oxygen in the oxymuriatic acid. The proper proportions for the complete success of this experiment are two measures of carbonous oxyd, and 2½ measures of oxymuriatic acid. A mixture, thus proportioned, being kept for 24 hours in a ground stoppered vial, and, for further security, inverted in mercury, when opened in water will undergo an instantaneous absorption of about two-thirds, which is muriatic acid gas; the residue, by agitation with lime-water, will be taken up, with the exception of about 1/15th, which is a casual mixture of azot.

Oxyd of carbon, when heated with phosphorus, dissolves a portion, and then burns with a pale yellow flame. The phosphorus is neither deposited nor acidified by long standing, even when assisted by water.

The effect of hydrogen on the carbonous oxyd is very striking. When equal parts of these gasses are mixed together and passed through a glass tube made red hot, a complete decomposition takes place, the gaseous oxyd deposits its charcoal on the inside of the tube, which, being nearly melting, causes it to adhere, and to form a brilliant, uniform, black enamel; while the oxygen of the gaseous oxyd by union with the hydrogen forms water, which is condensed at the further end of the tube. Some of the hydrogen passes through apparently unaltered.

The decomposition of carbonic acid gas, by means of electricity, when in contact with mercury or any other easily oxydable metallic body, well illustrates the nature of carbonous oxyd. Dr. Priestley was the first who found a change to take place in carbonic acid gas by taking the electric spark in it repeatedly for a considerable time. Out of many experiments, the following may be selected. In a small tube containing about 1/15th of an ounce measure of carbonic acid, and standing over mercury, the electric spark was taken for the space of an hour; after which the whole tube was clouded by a pulverulent matter of a black colour in the upper part of the tube, but yellow at the bottom, like sulphur. This substance, on examination, proved to be oxyd of mercury. The air itself was a little enlarged, and about a fifth part of it was rendered insoluble in water.

The elegant experiments of Th. de Saussure have thrown much light on this subject. Electric sparks were taken for 18 hours in a glass tube containing 13 cubic inches of dry and pure carbonic acid gas and confined by mercury. After electrization much black oxyd of mercury was discovered; a very slight dilatation amounting to no more than 1/15th of a cubic inch was observed. On throwing up some caustic alkali no more than one cubic inch was absorbed, which was therefore carbonic acid; the next was very pure oxyd of carbon, for where 100 parts of it were burnt with about a third of oxygen gas no water was perceived, the product being merely carbonic acid.

Carbonic acid has also been decomposed by the same ingenious chemist by hydrogen, by aid of the electric spark. In a long glass tube were mixed together 3½ measures of pure carbonic acid with an equal quantity of hydrogen, and the whole was electrized for twelve hours. A condensation

took place, considerable at first, but very trifling towards the conclusion of the process. A number of fine drops of water were deposited on the upper part of the tube, and the gaseous mixture was reduced in bulk from $7\frac{1}{2}$ measures to $4\frac{1}{2}$, of which one was undecomposed carbonic acid, and the remaining $3\frac{1}{2}$ were carbonous oxyd, containing a small admixture of hydrogen. In the above experiment the hydrogen appears to unite with part of the oxygen of the carbonic acid, to form the water, which is condensed, while the carbonic acid, by losing oxygen, passes to the state of carbonous oxyd.

A similar decomposition of carbonic acid by hydrogen also takes place when the mixed gases are passed through a red hot porcelain tube, and the gaseous oxyd is produced.

§ 3. Of hydrocarbonat, or carburetted hydrogen.

In the former section we have treated of the combination of carbon with a less portion of oxygen than is required for its acidification; in the present section we shall examine the phenomena attending the combination of carbon with hydrogen. Carburetted hydrogen, otherwise called *heavy inflammable air*, is an inflammable gas considerably heavier than hydrogen, but lighter than carbonous oxyd, or common air: it does not render lime-water turbid, when agitated with it, and by combustion with oxygen is totally resolvable into carbonic acid and water.

Before it was suspected that carbon could exist in any other state of oxygenation than carbonic acid, it might be inferred, with tolerable though not absolute certainty, that when any gas had been purified from carbonic acid by means of alkali or lime-water, if it furnished a fresh portion of this acid after combustion with oxygen, the carbonaceous ingredient existed in the state of pure carbon or charcoal. Therefore, as the only products of carburetted hydrogen, when burnt with oxygen, are carbonic acid and water, chemists generally satisfied themselves with estimating the quantity of carbon contained in the gas, by taking about 28 per cent. of the carbonic acid produced, and set down the entire remainder as hydrogen. For example, if 100 cubic inches of any gas, weighing 15 grains, were totally resolvable into carbonic acid and water, by combustion with oxygen; and if, by the combustion, 54 inches of carbonic acid, weighing 25 grains, were produced, the quantity of carbon originally contained in the gas would be reckoned to be seven grains, (being 28 per cent. of the weight of the carbonic acid,) and the difference between 7 and 15, or eight grains would be considered as the weight of the hydrogen; or, in other words, the gas would be called a carburetted hydrogen, consisting of hydrogen holding carbon in solution, in the proportion of eight, by weight, to seven of the latter.

But, it is obvious, that this mode of estimating must be totally erroneous in the case (probably very frequent), of a mixture of gaseous oxyd of carbon and hydrogen gas; and hence no approach to analysis can be obtained without ascertaining both the water and carbonic acid produced, and even then various causes of uncertainty will occur.

So that it is possible, and by no means improbable, that there may exist three species of gases, all of which have a claim to the title of hydrocarbonat, or carburetted hydrogen, namely, 1st. hydrogen, simply holding carbon in solution, or what corresponds with the original idea of a hydrocarbonat; 2d. hydrogen mixed with gaseous oxyd of carbon; 3d. a mixture of the two former species, or hydrogen and gaseous oxyd of carbon with an excess of carbon held in solution by one or both of these gases.

Carburetted hydrogen is obtained in a great variety of ways,

and with very considerable differences in specific gravity and the proportion of ingredients. It is found native on the surface of stagnant waters, marshes, wet ditches, &c. through which, if examined closely, large bubbles will be seen to rise in hot weather, and may be increased at pleasure by stirring up the bottom with a stick. In close, still evenings, if a candle be held over the surface, flashes of a blue lambent flame may be perceived spreading to a considerable distance. All that is not fabulous in the *ignis fatuus* is probably derived from this source. This species may be termed, for distinction, the carburetted hydrogen of marshes: in the pure form in which it can be collected it is usually mixed with about 25 per cent. of azot.

This gas is also given out very abundantly by almost every vegetable substance that is exposed to a dry heat sufficient for its decomposition. When heated in close vessels much more hydrocarbonat is obtained than by combustion in the open air, the product in this latter case containing more carbonic acid. It would be endless to enumerate the vegetable sources of this gas, but we shall mention some of the most convenient modes of obtaining it in a state of purity.

One of the commonest methods employed is the destructive distillation of the acetous salts. For this purpose, let a small proportion of dry acetate of potash be heated in a glass retort. The salt soon melts in its water of crystallization, puffs up, and, if the retort is too small, is very apt to come over into the neck. The first products are water and the air of the vessels; but, when the acetous acid begins to be scorched, a large stream of gas begins, and continues till the whole is red hot, and little else remains in the retort but carbonated alkali and a little charcoal. Along with the gas there arises much oil, which is condensed in the cool receiver. The gas, according to the analysis of it by Dr. Higgins, after the first portions have passed over, consists of nothing but hydrocarbonat and carbonic acid, which last may be separated by lime-water. The hydrocarbonat itself varies considerably. The first part is much heavier than the last, (though still lighter than common air,) and appears to hold in solution part of the oil; for, on standing some time over water, it becomes lighter, and is found to require less oxygen for saturation than before. The average specific gravity of the first and last gas mixed is to that of common air as two to three.

Carburetted hydrogen is obtained in great purity by sending the vapour of inflammable vegetable matter through an earthen or glass tube passing through a furnace, and kept red hot in the middle. The vapour of camphor, ether, alcohol, and other inflammables thus treated, is converted into this gas, but with much difference in quantity, according to the degree of heat and other circumstances.

Another method of obtaining carburetted hydrogen, is to put coal, wood, peat, &c. into any convenient vessel, an earthen or iron retort for example, and heat it slowly to redness.

Most animal inflammable substances, such as silk, fat, wax, and the like, yield this gas as freely as vegetable matter, by a similar treatment. This was discovered by Berthollet, in his masterly researches on the nature of animal matter and ammonia.

Carburetted hydrogen (or at least a gas that gives water and carbonic acid by combustion with oxygen), is also generated in abundance, when charcoal, without previous drying, is heated *per se* in close vessels, and continues to be given off till the charcoal has been in a state of full ignition for about an hour; after which it ceases, and the charcoal, as already mentioned, is rendered pure. A similar process of obtaining

this gas, is to inclose powdered charcoal in a tube passing through a furnace, to confine the charcoal by a pellet of clay loosely fixed at each extremity of the tube, and in that situation to send through it the vapour of water kept boiling in a small retort attached to one end of the tube. Much carbonic acid gas is generated this way, and, when this is separated by lime-water, the residue is inflammable.

Lastly, this gas may be procured by the direct union of its constituent parts. If hydrogen gas is passed seven or eight times successively through an iron tube containing charcoal, and heated red hot, a diminution of bulk takes place, the hydrogen dissolves a portion of the charcoal, and then assumes the properties of carburetted hydrogen.

A curious variety of hydrocarbonous gas, was discovered by the associated Dutch chemists (Van Dieman, Troostwyck, and others) which is procured from ether or alcohol, and has the remarkable property of generating an oil when mixed with oxymuriatic acid gas. Hence it has been termed *oily carburetted hydrogen*, or *olefiant gas*. The mode of preparing this singular gas, and the enumeration of its distinguishing properties, will form the subject of the next section; it may, however, be observed here, that according to Mr. W. Henry's experiments, the olefiant gas appears also to be contained in part in the hydrocarbonat from coal, wax, and some other substances, and greatly to contribute to the quantity of light and heat which these gasses give out as well as to their large proportion of carbonic acid.

Carburetted hydrogen is singularly affected by the electric spark. Dr. Aulstin found, that on taking the electric spark repeatedly through this gas, obtained from acetite of potash, the bulk of the gas enlarged after every shock, and at length expanded to nearly twice its original dimensions. When examined after this expansion, it was found to be as inflammable as before, and judging from the test of lime-water no carbonic acid appeared to have been generated. Dr. A. concludes that the enlargement can only be owing to the production of a quantity of hydrogen, and makes some inferences which, however, have since been shown by Mr. W. Henry to be erroneous. Mr. H. demonstrates that there is no destruction of carbon by this process, since the same quantity of carbonic acid is produced after as before electrization by the action of oxygen gas. He likewise makes it appear probable, that the water held in solution by the gas is the chief agent in its expansion, since when the gas has been dried by caustic alkali no continuance of electrization will enlarge it more than one sixth of its original bulk; but when the contact of water is admitted, the bulk is doubled by the same treatment. Perhaps the discovery of carbonous oxyd will explain this fact. It is not improbable that the carbon of the gas may unite with the oxygen of the water, and thus produce the carbonous oxyd which would not give any precipitate with lime-water, and the bulk of the gas would be enlarged both by the carbonous oxyd and the hydrogen of the water, as well as by the expansion which the hydrocarbonat would undergo after the carbon was separated from it, whilst the actual quantity of carbon remaining the same, as much carbonic acid would be separated by complete oxygenation as before electrization. It is not improbable that the affinities of hydrogen and carbon for oxygen are so nearly equal, that either substance is able partially to decompose the complete oxyd of the other. Thus we find, that when hydrogen and carbonic acid are together subjected to electricity, the carbonic acid is partially decomposed, and the product is carbonous oxyd and water, and on the other hand, when water is decomposed by red hot charcoal, a part of the product is also the carbonous oxyd.

All the hydrocarbonats are fatal to animal life; not at appears from the mere absence of oxygen, but from the presence of something positively noxious: since animals immersed in it die sooner than they would from the mere interruption of respiration.

This gas is scarcely if at all absorbed by water, but by long standing over it deposits a part of its carbon. This, however, applies only to those hydrocarbonats that require at least their own bulk of oxygen to saturate them, and especially to that variety called olefiant gas.

Simple carburetted hydrogen, when set fire to, burns at the surface in contact with the air with a blue flame with red edges, but when mixed with any of the olefiant gas the flame becomes much more brilliant, resembling that of oil. When applied to the purposes of illumination the hydrocarbonat from coal, from lamp-oil, or from wax, produces as much light in an Argand lamp as oil in substance does; this appears to be owing to the olefiant gas which they contain. The brightness of the flame is much diminished when these gasses have been kept over water, and hence for illumination they should be used as soon as prepared.

The combustion of hydrocarbonat is much more brilliant in oxygen gas, and the products if a sufficient quantity of oxygen has been used, are merely water and carbonic acid.

If any of the hydrocarbonats be mixed with oxygen gas and fired in a close vessel by the electric spark, or in any other way, an explosion takes place more or less violent according to the quantity of carbon contained in the gas, and the result of the decomposition is carbonic acid, together with any unconsumed gas or excess of oxygen, while the water is found condensed in drops on the sides of the jar. A single cubic inch of the mixed air is generally as much as can be conveniently managed at each explosion, and when any olefiant gas is present even this small quantity will endanger very thick glass jars; a very vivid red flame appears at the moment of explosion, and a great instantaneous enlargement takes place, after which the bulk is suddenly reduced to much less than its original quantity. When the carbonic acid is absorbed, if the gasses have been properly proportioned, no gaseous residu is left except accidental impurities.

The oxymuriatic acid furnishes also a very useful method of decomposing and analysing all the hydrocarbonats. Mr. Cruickshank's beautiful and accurate experiments on this subject are highly instructive. The oxymuriatic acid gas was procured from oxymuriat of potash, by means of muriatic acid, and was used soon after being prepared, as it is in some degree altered by keeping.

Pure hydrogen and oxymuriatic acid gas were first tried; one measure of the former with two of the latter mixed in a glass vial with a ground stopper, and inverted over water were suffered to remain 24 hours. The stopper being then withdrawn, the water rushed into the vial, absorbing the whole of its gaseous contents, except about $\frac{1}{5}$ of the whole, which was azot, and doubtless a casual impurity.

The different hydrocarbonats were then tried. In a bottle filled with, and inverted over water, one measure of well washed hydrocarbonat from camphor was mixed with two of oxymuriatic acid. A slight cloud and trifling absorption were perceived at the time of mixture, after which the stopper was put in, and the whole was left at rest for 24 hours. When opened under water all the gas was absorbed, except 0.43 of a measure, and this was reduced by lime-water to 0.34. This residue was still inflammable, but burnt with a lambent blue flame like carbonous oxyd; and

this it was proved for the most part to consist of, by the large quantity of carbonic acid which it yielded when fired with oxygen; two parts of it with one of oxygen yielding no less than 1.7 of carbonic acid.

In the above experiment the mutual decomposition of the oxymuriatic acid and carburetted hydrogen, produces no less than four new compounds: namely, common muriatic acid by the loss of oxygen; water by the union of oxygen with hydrogen; carbonous oxyd by the partial oxygenation of some of the carbon; and carbonic acid by the complete oxygenation of the remainder.

On increasing the quantity of oxymuriatic acid to about four times that of the carburetted hydrogen, the whole of the carbon was now found to be completely oxygenated, and every thing was absorbed by water or lime-water; the products were therefore only muriatic and carbonic acids and water.

Mr. Cruickshank found a very considerable difference in the quantity of carbonic acid produced, and of course in the carbonaceous ingredient in the hydrocarbonats from camphor, ether, and alcohol, when they had been long kept over water or agitated with it. A similar difference in the quantity of combustible matter was observed by Dr. Higgins, in the hydrocarbonat from acetite of potash, which renders it highly probable that these hydrocarbonats hold in solution somewhat of an oily ethereal vapour, or a portion of true olefiant gas which water will absorb. This also, it probably is, which causes the slight diminution which some of the hydrocarbonats immediately experience when mixed with oxymuriatic acid gas; for with pure olefiant gas the diminution is great and immediate, as we shall presently mention. When oxymuriatic acid gas and carburetted hydrogen are mixed in the proportion of two of the former to one of the latter, and the mixture is exploded by the electric spark, a copious deposition of charcoal takes place, but when oxymuriatic acid gas is used in a larger quantity, the whole of the carbon is converted into carbonic acid. This separation of charcoal takes place only with the hydrocarbonats from camphor, ether, and alcohol, and even in these this property is lost by being kept some time over water.

Carburetted hydrogen is also readily decomposed by sulphur; the carbon being precipitated in form of a black powder, and the hydrogen uniting by preference with the sulphur forming hepatic gas. This may be most conveniently effected by making sulphur red hot in an earthen tube and then passing the carburetted hydrogen through it.

§ 4. Of olefiant gas.

The discovery of this singular species of carburetted hydrogen is due to some associated chemists of Amsterdam, (Van Dieman, Van Troostwyck, Bondt, and Lawrenburgh,) and originated in their examination of the different products of the distillation of sulphuric acid and alcohol, in the preparation of ether. In the common process this gas appears towards the latter end of the distillation accompanied by the oil of wine; but in order to procure it immediately, for the purpose of experiment, nothing more is necessary than to put into a proof bottle a little rectified alcohol, and four times its weight of strong sulphuric acid; much heat is given out on mixture; the colour becomes first brown, and then black, and on the application of a gentle heat the gas in question is produced in vast abundance, and may be collected in jars inverted over water. The only foreign matters with which the gas is mixed are sulphureous acid, and a little ether, but these may be got rid of by washing it with some very dilute liquid ammonia, and then the olefiant gas remains pure.

When thus prepared it exhibits the following properties. Its specific gravity is to that of atmospheric air, as 905 to 1000. Its odour is very fetid. It burns with a dense flame, like an oil or resin. It is not absorbed nor altered by water, nor is it affected by any of the common reagents, whether gasses, alkalies, or acids, except the oxymuriatic acid gas. Equal parts of these gasses being mixed together, an immediate diminution of bulk takes place, a visible vapour fills the vessel, much heat is given out so as to be very sensible even to the hand, and at the same time a thick pearl-coloured oil appears in drops on the surface of the water, over which the mixture is made, and immediately sinks to the bottom.

It is from this singular production of dense oil, with the oxymuriatic acid, that this species of carburetted hydrogen has acquired the name of *olefiant* or *oil making*. When these two gasses are mixed in the proportion of four of oxymuriatic acid to three of carburetted hydrogen, the whole is absorbed, except accidental impurities.

The oil thus generated is heavier than water, whitish, and semi-transparent. By keeping it becomes yellow and limpid; its odour is highly fragrant and penetrating; its taste is somewhat sweet. It is sparingly soluble in water, to which it communicates its peculiar odour. Caustic potash has no effect on the oil, but separates the adhering muriatic acid and renders it more fragrant.

The constituent parts of olefiant gas appear to be only carbon and hydrogen, but it contains a larger proportion of the former than the common hydrocarbonats do. It is decomposed by sulphur like the other hydrocarbonats.

The combustion of this gas offers some curious circumstances. When an Argand lamp is supplied with it instead of oil, the flame far exceeds every oil and hydrocarbonat in beauty and brilliance. When mixed with oxygen gas, and detonated by the electric spark, the explosion is much more violent than that of common carburetted hydrogen. Mr. Henry found that a strong glass tube was shattered with only 0.3 of a cubic inch of olefiant gas, and 0.17 of oxygen; but when the quantity of oxygen is considerably below that required, for the complete saturation of this gas, only a very trifling explosion is produced.

Another singular property of olefiant gas is the copious deposition of charcoal, when it is mixed with a small quantity of oxygen or oxymuriatic acid gas and kindled. After the mixture of the olefiant and oxymuriatic acid gasses, two or three minutes elapse before the oil thus generated is entirely precipitated, but if this mixture is immediately set fire to there is no production of oil; but in its stead so copious a deposition of charcoal takes place, that the whole vessel is obscured, as if it had been lined with lamp-black.

A similar deposition of carbon takes place when the olefiant gas is mixed with just enough of oxygen to begin the combustion. If two parts of the latter are mixed with 1½ of the former, and the mixture set fire to by the electric spark, a copious deposition of carbon ensues.

The great excess of carbon contained in olefiant gas is also manifest from the large proportion of oxygen required for its saturation, amounting to 2.84 to one, estimating each by bulk.

Olefiant gas has also been procured by the Dutch chemists, above named, not only from alcohol and sulphuric acid, but by passing the vapour of alcohol or ether through a red hot earthen tube. In this case, however, the olefiant gas appears to be mixed with a little carburetted hydrogen. It is remarkable, that if a glass tube be used instead of an earthen one, the gas is no longer olefiant, but only simple carburetted hydrogen; but if the glass tube is filled with

either alumine or flint the same effect is produced as with the earthen tube; on the other hand, when lime either pure or carbonated, or magnesia, were substituted to the two other earths, the gas was common carburetted hydrogen.

The whole of this very interesting part of chemistry requires further examination, especially as far as regards the formation of carbonous oxyd.

CARBON, in reference to *Husbandry and Gardening*, a matter obtained from different animal and vegetable substances, by means of a slow and confined combustion. This substance is charcoal in its pure state; that which is commonly met with containing a portion of incombustible earth, and some saline matter in union with the carbon. See CARBON and CHARCOAL.

The author of the "Philosophy of Agriculture and Gardening," remarks, "that when animal and vegetable bodies are burnt without the access of air, that is, where their volatile parts are sublimed, there remains a greater quantity of charcoal, a much greater in vegetable bodies than in animal ones. This is termed carbon by the French school, when it is quite pure, and is now known to be one of the most universal materials of nature: and as vegetable bodies contain so much of it in their own composition, they may be supposed to absorb it entire where they grow vigorously, especially as it is a simple material: but they may possibly form it also from water and air within their own vessels, when they are excluded from access to it externally. The whole atmosphere contains always a quantity of it in the form of carbonic acid, or fixed air; as is known by the scum which presently becomes visible on lime water when exposed to the air, and which consists of a reunion of the lime with the carbonic acid, which may therefore be said to encompass the earth. The simplicity of carbon as an elementary substance was disputed by Dr. Austin, who believed he had decomposed it. But Mr. Henry, by accurately repeating his experiments, has shown the fallacy or inconclusiveness of them, as may be seen in the Philosophical Transactions for 1797. And it is added that a further great reservoir of carbon exists in lime-stone, in the form of carbonic acid; which when the stronger acid is poured on, the calcareous earth becomes a gas, acquiring its necessary addition of heat from that which is given out in the combination of the stronger acid with the lime. It also acquires its necessary heat when lime-stone is burnt, from the consuming fuel, rising in the form of gas, and is dissipated in the air; and probably soon settles on the earth as it cools, as it is considerably heavier than the common atmosphere. But the great source of carbon exists in the black earth which has been lately left by the decomposition of vegetable and animal bodies; and is then in a state fit to combine with azote or nitrogen, and with oxygen, when exposed to those two gasses, as they exist in the atmosphere, and is thus adapted either to promote the generation of nitrous acid, or to form carbonic acid, and thus to assist vegetation. Morasses consist principally of the carbonic recrements of vegetable matters, which are gradually decomposed in great length of time into clay, with argillaceous sand, such as is found over coal beds, and some calcareous earth, as in marl, and lastly, with some iron and fossil coal. These by elutriation are separated from each other, and form the strata of coal countries. In other places they remain intermixed, as they were probably produced from the decomposition of vegetables and terrestrial animals; and form what in books of practical agriculture is called a *loamy* soil, consisting of carbonic matter, sand, and clay, with a portion of iron. It has always been observed, that this black garden mould, or earth produced from the recrements of vegetables, is capable of absorbing a much greater quantity of putrid effluvia than

either air or water, and probably of combining with its ammonia, and producing a kind of *hepar carbonis*, and thus facilitating vegetation. The practice of burying dead bodies so few feet below the surface is a proof of this; as the putrid exhalations from the carcase are retained, and do not penetrate to the surface. On the same account, the air over new ploughed fields has long been esteemed salutary to invalids, or convalescents, as it probably purifies the supernatant atmosphere. But it was not till lately known that carbon, or charcoal, absorbs with such avidity all putrid exhalations; if it has been recently burnt, and has not been already saturated with them: inasmuch that putrid flesh is said to be much sweetened by being covered a few inches with the powder of charcoal, or even for being buried for a time in black garden mould; as putrid exhalations consist chiefly of ammonia, hydrogen, and carbonic acid, and are the immediate products of the dissolution of animal or vegetable bodies; they are believed to contribute much to vegetation, as whatever materials have constituted an organic body may again, after a certain degree of dissolution, form a part of another organic body. The hydrogen and azote produce ammonia, which combining with carbon, may form an *hepar carbonis*, and by thus rendering carbon soluble in water, may much contribute to the growth of vegetables. It has been said, that some morasses have prevented the animal bodies which have been buried in them from putrefaction; which may in part have been owing to the great attraction of the carbon of the morass to putrid effluvia, and in part, perhaps, to the vitriolic acid which some morasses are said to contain in their constitution."

"Then here occurs," says the author, "an important question. By what other means is the solid carbon rendered fluid, so as to be capable of entering the fine mouths of vegetable absorbents? The carbon, which exists in the atmosphere, and in lime-stone, is united with oxygen, and thence becomes soluble or diffusible in water; and may thus be absorbed by the living action of vegetable vessels; or may be again combined by chemical attraction with the lime, which has been deprived of it by calcination. When mild calcareous earth, as lime-stone, chalk, and marble, has been deprived of its water, and of its carbonic acid by calcination, it becomes lime. Afterwards, when it is cold, if water be sprinkled over it, a considerable degree of heat is instantly perceived, which is pressed out by the combination of a part of the water with the lime; as all bodies when they change from a fluid state to a solid one, give out the heat which before kept them fluid. At the same time, another part of the water which was added, is raised into steam by the great heat given out, as above mentioned, and the expansion of this steam breaks this lime into fine powder, which otherwise retains the form of the lumps of lime-stone before calcination. But if too great a quantity of cold water be suddenly added, no steam is raised, and the lump of lime-stone retains its form, whence it happens, that some kinds of lime fall into finer powder, and are said to make better mortar, if slaked with boiling water, than with cold. On this account, the lime which is designed to be spread on land should previously be either laid in a heap, and either suffered to become moist by the water of the atmosphere, or slaked by a proper quantity of water: otherwise, if it be spread on wet ground, or when so spread is exposed to much rain, the heat generated will be dissipated without breaking the lumps of lime into powder, which will then gradually harden again into lime-stone, disappoint the expectations of the agricultor, and afflict him with the loss of much labour and expence. When the powder of slaked lime, mixed with sand and water, is spread on a wall, that part of the water which is not

necessary for its imperfect crystallization, evaporates into the air, and the lime then gradually attracts the carbonic acid, which is diffused in the atmosphere: but as he supposes this carbonic acid is dissolved in the water, which is also diffused in the atmosphere, the lime is perpetually moistened by this new acquisition of water from the air, as that which before adhered to it, and had parted with its carbonic acid, evaporates. On which account, new built walls are months, and even years in drying, as they continue to attract water along with the carbonic acid from the air, which stands upon them in drops till the lime regains its original quantity of carbonic acid, and again hardens into stone, or forms a spar by its more perfect, or less disturbed manner of crystallization. It is consequently supposed, that the earth acquires carbon, both in a manner similar to the above, by its attracting either the carbonic acid, or the water in which it is diffused, from the atmosphere, and also by the specific gravity of carbonic acid gas being ten times greater than that of common air: whence, there must be constantly a great sediment of it on the surface of the earth, which in its state of solution in oxygen and water may be readily drank up by the roots of vegetables. Another means by which vegetables acquire carbon in great quantity, may be from lime-stone dissolved in water, which though a slow process, occurs in innumerable springs of water, which pass through the calcareous or marly strata of the earth; as those of Matlock or Bristol in passing through lime-stone, and those about Derby in passing through marl; and is brought to the roots of vegetables by the showers which fall on soils where marl, chalk, lime-stone, marble, alabaster, and fluor, exist, which include almost the whole of this island.

By this solution of mild calcareous earth in water, not only the carbon in the form of carbonic acid, not yet made into gas, but the lime also with which it is united, becomes absorbed into the vegetable system, and thus contributes to the nutriment of plants, both as so much calcareous earth, and as so much carbon.

And another mode may be by the union of this simple substance, with which all garden mould abounds, with pure calcareous earth into a kind of *hepar*, analogous to the *hepar* of sulphur made with lime, which abounds in some mineral waters, and this is supposed to be the great use of lime in agriculture."

For the purpose of ascertaining the probability of this mode of solution of carbon, the following experiment was made. "About two ounces of lime in powder was mixed with about as much charcoal in powder, put into a crucible, and covered with about an inch or two of siliceous sand. The crucible was kept red hot for an hour, or longer, and then suffered to cool. On the next day water was poured on the lime and charcoal, which then stood a day or two in an open cup, and acquired a calcareous scum on its surface. And though it had not much taste, except that of the caustic-

ticity of the lime, yet on dropping one drop of marine acid into a tea spoonful of the clear solution, a strong smell like that of *hepar sulphuris* was procured, or like that of Harrowgate water, which evinced that the carbon was thus rendered soluble in water. Hence, the doctor suggests, that the sulphureous smell of Harrowgate and Kiddleston waters, and other similar springs, may be owing to the union of the alkali of decomposing marine salt, with the carbon of the earth they run through, and that this kind of water might thus possibly be used as a profitable manure in agriculture."

And a still further method by which vegetable roots acquire it, is suspected to be "by their dissolving carbonic acid from lime-stone in its fluid, not its gaseous state, which the lime-stone again attracts from the atmosphere, and consolidates, and forms other matters included in the soil. First because lime is believed by some agricultors, who much employ it, to do more service in the second year than the first, that is, in its mild state, when it abounds with carbonic acid, than in its caustic state, when it is deprived of it. Secondly, that the use of burning lime seems hence to be simply to reduce it to an impalpable powder, almost approaching to fluidity, which must facilitate the application of the innumerable extremities of vegetable fibres to this incalculable increase of its surface; which may thence acquire by their absorbent power, the carbonic acid from these minute particles of lime, as fast as they can recover it by chemical attraction from the air or water, or other inanimate substances in their vicinity. Thirdly, the hyperoxygenation of the perspirable matter of the plants, which thence gives up oxygen gas in the sunshine, would induce us to believe that a great part of the carbon which furnishes so principal a part of vegetable nutriment, was received by their roots in the form of carbonic acid; and that it becomes in part decomposed in their circulation, giving up its oxygen; which thus abounds in the secreted fluids of vegetables from this source, as well as from decomposed water, as is generally known. And lastly, there is another way by which carbon is received into the vegetable system, which is by its existence in sugar and in mucilage, both of which are taken up undecomposed, as appears by their presence in the vernal sap-juice, which is obtained from the maple and the birch, which like the chyle of animals, is absorbed in its undecomposed state by the roots of plants." This matter must of course be considered as one of the principal constituent parts of vegetables; and would seem to enter into, and accumulate in the constitutions of plants in proportion to their successive growth. Some plants, however, take more into their composition than others, as from the result of chemical analysis, a quantity almost equal to all their other component parts has been found in particular instances, as in *agaricus piperatus*, *clavaria aurea*, *agaricus*, *lycoperdon tessellatum*; while in others, only a very small portion."

Carbonic Acid

CARBONIC ACID, CARBONIC ACID GAS, or fixed Acid.—Aerial acid.—Mephitic acid.—Kohlensäure, Germ.—Acide carbonique, Fr. in *Chemistry*.

Carbonic acid, in its uncombined state, is **only** known to us as a gas, and it is the first gas in which acid properties were clearly discovered. It is known to be so by **reddening** certain vegetable blues, by neutralizing alkalies and **alkaline** earths, and by being formed by the union of a combustible base.

The sources of this acid are immense, and **widely** diffused. The chief are the following.

1. The atmosphere always contains a small portion, which varies in the immediate vicinity of places where the processes of respiration and combustion are going on, though somewhat less than might be expected. The general average is estimated at about one hundredth part. It is readily extracted from a confined portion of the atmosphere by the contact of lime or the caustic alkalies.

2. Almost every natural spring, as it rises from the earth, contains a portion of this air; and some waters hold so large a portion as to give them, when exposed to the air, a very brisk, frothy appearance, and a very sensible taste and decidedly acid properties. The celebrated springs of Spa, Pyrmont, and Seltzer, are of this kind, and the most highly carbonated water of them contains about its own bulk of the gas.

3. Every process in which coal, wood, or any other carbonaceous substance is burnt, is one which generates this acid gas. The same may be said of the process of respiration.

4. The vegetation of plants under some circumstances generates carbonic acid.

5. The spontaneous decomposition of vegetable and animal matter produces this gas in abundance; hence fermentation and putrefaction are carbonating processes.

6. But the largest store of carbonic acid that exists is that enormous quantity which is solidified in all the immense beds of lime-stone, chalk, and calcareous stones with which every part of the globe abounds. Many of these contain 40 per cent. or even more of their *weight* of this acid.

Carbonic acid gas, or fixed air, has the following properties. It is permanently gaseous at any temperature or pressure. It is fatal to animal life, any living creature immersed in it perishing as soon as it would by total interruption of respiration. Hence the small, warm-blooded animals die in it almost immediately; dogs, and animals of bulk, speedily become senseless in it, but recover, if removed in a short time; frogs, and cold-blooded animals, live in it for a considerable time, owing to their power of subsisting for a time without external respiration; but when this is past they perish as the warm-blooded animals. This air is equally incapable of maintaining combustion, so that a candle let down into a jar of it is extinguished as soon as it enters the gas as effectually as if dipped into water. Even the admixture of so small a proportion as one-ninth of carbonic acid gas renders common air unable to maintain combustion, according to Mr. Cavendish's experiments. It is the heaviest of all the known gases, except the sulphureous. Hence, as soon as generated, it falls through the atmosphere to the lowest places, unless mingled with it by agitation or long standing. Thus, if a jar of fixed air is inverted from some little height over a burning taper, enough of it falls unmixed upon the taper to extinguish it. The weight of this gas is,

in all circumstances of pressure and temperature, to that of common air very nearly as three to two; hence its specific gravity will be about .001806, and the weight of a cubic inch at 60° therm. and 29.5 inch bar. will be about .456 of a grain.

This gas also combines readily with water and many other substances, as will be presently mentioned. Its combinations with the alkalis, earths, and metals, are called *carbonats*.

Carbonic acid gas is procured, for experiment, generally from lime-stone, chalk, marble, or any carbonat of lime, either by heat or by the action of an acid, almost any of which will dislodge the carbonic from its bases, and cause it to assume a gaseous form. The mild alkalis may also be used for this purpose. The action of acids always produces an effervescence, or frothing at the surfaces of contact, owing to the rapidity with which the carbonic acid takes the form of a gas; and hence all stones that effervesce with acids may be presumed (with but few exceptions), to consist chiefly of carbonat of lime. To obtain carbonic acid gas in quantity and in a regular, uniform stream, put a number of small lumps of marble or calcareous spar in any proper vessel, pour on them sulphuric or rather muriatic acid diluted, and receive the gas as it is generated. If it is collected over water, some will be lost at first, owing to the absorption of a portion by the water itself. Or else, put some dry chalk or marble, or especially carbonat of magnesia, in an earthen retort and heat it to redness. The carbonic acid gas then comes off in abundance. When decomposed by acids, a grain of marble will yield nearly a cubic inch of gas.

As all mixtures under the vinous fermentation, give out an abundance of this gas, this affords a ready way for procuring it, and substances under experiment may be immersed in an atmosphere of the gas by being simply suspended over the fermenting vats of brewhouses.

Carbonic acid gas is readily absorbed by water; and thus the natural carbonated waters may be easily imitated. This fluid has a pungent, agreeable, brisk taste, and bubbles vigorously, when exposed to air, the more in proportion to the temperature. This absorption is shewn in a very easy manner, simply by filling a phial with water, then displacing about half its contents, by throwing up the gas, and then pressing the finger close against the mouth, shaking the half-full bottle violently. It will then absorb so much of the gas as to make nearly a vacuum within, which will be felt by a strong external pressure of the atmosphere on the finger that shuts the communication. This absorption is also equally promoted by subjecting the gas to strong pressure, when in contact with the water that is to absorb it; and it is by the united action of pressure and agitation that the manufacture of the carbonated medicinal waters (such as the artificial Seltzer, and the like), is carried to such great perfection.

Water, at about 50° temperature, will absorb, by mere agitation, nearly its own bulk of carbonic acid gas; but by the combined action of pressure and agitation, three times as much may be thrown in.

Mr. William Henry, in his valuable experiments on the absorption of gases by water, (Phil. Trans. for 1803,) has shewn that the quantity of gas absorbed is (*ceteris paribus*), regulated by the purity of the gas; for, even if the gas itself is obtained unmixed with any other, some addition of atmospheric air must take place from the vessels in which the experiment is made, and also from the water, which cannot be absolutely purged of common air by boiling or any other method. Hence Mr. Henry found, that if 20 measures of nearly pure carbonic acid gas were agitated with 10 measures of water, full 10 measures of the gas would be absorbed;

but if 20 of the gas, mixed with 10 of common air, were agitated with the same quantity of water, only six measures could be taken up. Water also parts with a great proportion of its carbonic acid by mere exposure to air, which is independent of the circumstance of removing the mechanical pressure of corks, &c.; for Dr. Brownrigg found that the gas would not escape from Seltzer water, when in a close bottle, though a loose empty bladder supplied the place of a cork, and in which, therefore, the gas had ample room to expand itself; but a free communication with the air was necessary for this escape. The absorption of the gas is inversely as the temperature of the water; cold water absorbing much more than warm. The diminution of absorption, on raising the heat, Mr. Henry estimates at about $\frac{1}{11}$ th of the whole for every ten degrees above 55°. With regard to the effect of pressure, it appears that water, in all cases, takes up as great a bulk of condensed as of expanded gas, under similar circumstances of temperature.

Therefore, as the bulk of all aeriform bodies is inversely as the pressure to which they are exposed, the quantity absorbed is directly as the pressure; that is, for example, if a pressure of 30 inches of mercury will cause a certain bulk of carbonic acid to be absorbed, a pressure of 60 inches will cause a double absorption.

The specific gravity of water, holding its own bulk of carbonic acid, is about 1.0015. This gas is readily and almost totally again expelled by heat; hence, in the analysis of mineral waters, the first step to be in general pursued is the expulsion of the gases which it may contain, by boiling for about ten or fifteen minutes.

Carbonated water shews its acid properties by changing the colour of litmus from blue to red. This it will do, according to Bergman, when the water contains as much as $\frac{1}{18}$ th of its bulk of the gas. It is very conveniently shewn, in the way mentioned by Kirwan, that is, by adding, in a thin glass tube, or jar, about equal quantities of the carbonated water, and of litmus infusion diluted, so that the blue is just distinguishable. The colour then becomes of a very dilute red, and is better remarked when compared with a similar glass tube full of the same dilute litmus liquor and plain water. To shew that it is the carbonic and no other acid that produces this change, let some of the carbonated water be boiled strongly for a few minutes, and then it will leave the blue unaltered.

But lime-water is a much more delicate test for carbonic acid, either gaseous or liquid. When a gas is to be tried, nothing more is required than to shake it with lime-water, or with barytic or strontian water, and the immediate mildness of the water will indicate the presence of carbonic acid gas in almost every case.

But with liquid carbonated water, it should be remembered, that though the first portion of carbonic acid will precipitate the lime from its solution in the form of white carbonat of lime or chalk, a greater portion of the acid will re-dissolve the *carbonat of lime*. So that if a highly carbonated water and lime-water be mixed together at repeated portions, the mixture will first become turbid by the separation of the carbonat of lime; then an additional quantity of carbonated water will make it again clear by re-dissolving the carbonat; after which another portion of lime-water will again make it turbid, and fresh carbonated water again clear, and so on, in proportion to the mutual saturation and supersaturation of the two ingredients. Therefore, as no error can arise from an excess of lime-water, the latter, to shew, in all cases, the presence of carbonic acid, should be in equal quantity with the carbonated water. According to Bergman's valuable researches on carbonic (called by him *aerial*)

acid, lime-water will detect by its cloudiness as little as one cubic inch of the gas in 7000 grains of water, that is, where the weight of the gas is only $\frac{1}{14000}$ th of the whole.

This gas is also readily and totally absorbed from any gaseous mixture by slight agitation with a solution of caustic or nearly caustic alkali. A much smaller quantity of alkaline solution will suffice than of lime-water, as the former may be made much more concentrated. This is often convenient; but it is not so palpable a test, as the cloudiness or change of appearance in the alkaline solution enforces.

Carbonic acid, according to the modern system of nomenclature, signifies an acid whose basis is carbon; and hence that it is produced by the combustion or oxygenation of carbon or pure charcoal. It required the united efforts of many of the most eminent chemists to elucidate the nature of this important acid, and to shew that the very same substance which existed as a large component part of all calcareous stones, and was given off abundantly by many of the natural mineral waters, was also the sole product of the combustion of charcoal, and all carbonaceous matters. The full discovery and proof of this fact are due to Lavoisier, who made the elementary experiment of burning a given weight of charcoal in oxygen gas of known purity, (no other substance being introduced than a very minute portion of phosphorus to begin the combustion,) and found the product of the combustion to be this acid gas, the weight of which, when removed by caustic alkali, corresponded very exactly with the loss of charcoal and oxygen. Very little actual diminution of bulk takes place at first in this combustion, since the product is itself a gas, and not a liquid, as happens after the combustion of sulphur, phosphorus, &c. and therefore it is not till caustic alkali or lime-water is introduced that the production of the carbonic acid, and consequent loss of oxygen, are made apparent. From this elementary experiment, Lavoisier infers, that carbonic acid is composed of about 28, by weight, of charcoal, and 72 of oxygen, and the results of subsequent inquiries nearly, if not absolutely, confirm the accuracy of this statement.

Carbonic acid is at its highest state of oxygenation, and is the only state in which it has acid properties. United with less oxygen it forms the *carbonous oxyd* as noticed in the last article, in which, also, the partial disoxygenation of carbonic acid and consequent production of the carbonous oxyd are described.

Carbonic acid has been *completely* disoxygenated (that is, reduced to black pulverulent charcoal) by only one substance, namely, by phosphorus. This discovery was made by Mr. Tennant, and was followed by other valuable experiments by Dr. Pearson. (Phil. Trans. for 1791-2.)

From the well known fact that phosphorus cannot be made by distilling phosphat of lime and charcoal, the latter not having the power of decomposing this acid when united with lime, Mr. T. inferred that the united actions of phosphorus and lime might be sufficient to decompose carbonic acid by a stronger affinity with its oxygen. He accordingly put some phosphorus into a coated glass tube closed at one end, and over the phosphorus some powdered marble. The open end of the tube was then also closed, except a very

small aperture, to prevent the free access of the external air, and the tube was then heated red hot for a few minutes. When cold and broken it was found to contain a black powder consisting of true charcoal mixed with both phosphat and phosphuret of lime, together with some undecomposed marble. In this experiment the only source of the black carbonaceous powder can be the carbonic acid of the marble, which appears to have been decomposed by complicated affinities, namely by that of part of the phosphorus for the oxygen of the carbonic acid, of the rest of the phosphorus for the lime forming the phosphuret of lime, and also by the phosphoric acid (as soon as formed) for another portion of the lime forming the phosphat of lime. Or, in other words, the carbonat of lime must undergo two disuniting processes before the charcoal can be produced, namely, the carbonic acid must be separated from the lime to which it has a certain affinity, and also the oxygen of the carbonic acid must be separated from the carbon which is its base. The lime is detached from its union with the carbonic acid by the united affinities of part of the phosphorus for lime, and also of the phosphoric acid, when formed, for the lime. On the other hand, the carbonic acid is decomposed by the direct affinity of phosphorus for oxygen, which is great, but however of itself less than that of carbon for oxygen, since, in the common distillation of phosphorus, it is produced by decomposing phosphoric acid with charcoal. Therefore the decomposition of carbonic acid here produced is the result of combined affinities, and could only be effected in this manner.

Dr. Pearson decomposed carbonic acid by a similar process, but with phosphorus and carbonat of soda instead of carbonat of lime. Sufficient quantity of the black powder was procured in both cases to prove that it was genuine charcoal, and yielded carbonic acid again on combustion with nitre.

Many liquids absorb carbonic acid with apparently as much ease as water, such as alcohol, oil, &c. but such mixtures seem to produce no remarkable chemical change.

The affinity of carbonic acid with the alkalis, earths, and metals, is so weak that it may be displaced by every other acid, the boracic excepted. This weakness of affinity is doubtless much owing to the tendency which it has to assume a gaseous form as soon as disengaged.

The order of the affinities of this acid in the liquid way for the alkalis and earths is barytes, strontian, lime, potash, soda, magnesia, and ammonia. With regard to the two latter indeed, the force of affinity is so nearly balanced that each substance will partially decompose the carbonat of the other according to the temperature. Thus at a higher heat the ammonia, from its increased tendency to volatilization, loses much of its force of affinity with solid or liquid bases, and then its carbonat is decomposed by magnesia, which no heat can volatilize; but in a low temperature the affinity of the ammonia prevails and it decomposes the magnesian carbonat, though very imperfectly.

As the carbonic acid quits every substance in a high heat its relative affinities in the dry way cannot be ascertained.

Carpentry

CARPENTRY, in *Civil Architecture*. The art of carpentry is, in general terms, the art of employing timber in the construction of edifices. This is an art of the most general and important use, and of the highest antiquity; from the rude and solitary cabin to the rich and peopled city, in the earliest dawnings and the brightest periods of civilization, wherever nature has presented to man her forests, the building art has found in them a material of universal application, commodious and economical. Carpentry is also interesting to the fine arts, as its forms and operations have been the model of Grecian architecture, which has decorated and improved, but never renounced, its original type in wooden building. See the articles BUILDING and CIVIL *Architecture*.

With respect to the history of this art our information is short and scanty. Pliny and Vitruvius, the only writers upon the building arts whose works have reached modern times, confine their observations upon carpentry chiefly to the choice and felling of timber; and it may be readily conceived that ancient buildings preserve no specimens of an art which is not calculated to resist the injuries of time and the violences of rapine.

The remains of Egyptian architecture present, perhaps, the only example of a complete system of building without the use of timber, while, at the same time, arches and vaults were unknown; for many Roman edifices, such as the Pantheon, Temple of Peace, &c. might be quoted, which, by means of vaults, are independent of carpentry. In the Egyptian construction, however, flat roofs of maffy stone

were used, which it was necessary to support by thick-set avenues of columns, arranged at small equal distances over the whole area. This form, though sufficiently striking and picturesque, was of course incommodious, and only adapted to a dry climate. A pediment roof, therefore, was the first effort of constructive carpentry; this answered the purpose of an effectual shelter, by throwing off the humidity of the skies; at the same time, the rafters, in connexion with the transverse beams of the ceiling, formed a truss which would be gradually improved, and thus give the means of covering a wide space, without any other support than the external walls.

The invention of pediment roofs leads us naturally to Greece, where this member was an essential part of architecture. Besides forming roofs, the Greeks appear to have used carpentry in the framing of floors, and for rustic buildings and other purposes. But in a warm climate, abounding with stone and marble, it is not probable, that wood was much used in the internal finishing of any edifices, except for those objects wherein lightness and tenacity are essential qualities, as doors; though there are some remains of marble doors. *Museum Worsleyanum*.

This was less the case in Rome. The Romans seem to have used wood for nearly all the purposes of carpentry that the moderns are acquainted with. The roofs of buildings, the architraves, where they were very long, as in the Tuscan temples and other cases, the framing of floors, were all of this material. They also formed arches of slight timber grating

for stuccoing; they had wooden cornices, and the stone seats of theatres were covered with boarding. Vitruvius, l. 4. 1. 7. &c. We are told of considerable buildings, as amphitheatres, being erected of wood; such was that built by Augustus to exhibit the shows on account of the victory of Actium, and many others, at Rome and different parts of Italy. It may be remarked that the beams of the roof were generally left uncovered by a ceiling; and sometimes, in magnificent buildings, encrusted with bronze, and even gilded as in the basilica of St. Peter, erected by Constantine.

In the colder countries of Europe, wood was more plentifully used, particularly in the interior works; and in the middle ages the art of carpentry partook of the bold and skilful construction exhibited in that style of building commonly called gothic; of this the high pitched weighty roofs and lofty spires of the great cathedrals afford many striking instances.

In more modern times carpentry still improved. The wooden bridges of Palladio are examples of admirable construction. Some French artists too have given eminent instances of ingenious carpentry, as Philibert Delorme in his method of constructing wooden domes; and Moulneau in his, which was executed at the Halle du Bled, at Paris, and various centres for large stone arches by Peronnet, Hupéau, &c. In England the timber work of the dome and scaffolding of St. Paul's, and, in later times, many examples of centres, bridges and roofs may be cited as models of scientific carpentry; while in accuracy of execution, celerity and neatness of finishing, our workmen are unequalled. In the north of Europe, and particularly in Sweden and Norway, wood is almost the only material used for building; and of course the natives must have considerable practical skill in carpentry.

The art of employing timber in building is divided into two grand branches: carpentry and joinery. The first includes the larger and rougher kinds of work, and that part which is material to the construction and stability of an edifice; and, generally, all the work wherein the timber is valued by the cubical foot. Joinery, which is called by the French, menuiserie, from the menus bois, or small wood employed in that art, includes all the interior finishing and ornamental wood-work, and is valued by the superficial foot.

In this article we shall treat of the constructive part, or carpentry, strictly speaking, leaving what respects the material and belongs to architecture in general, as the choice of trees, the strength of timber, &c. to the article TIMBER. We shall therefore suppose the material arrived in the carpenter's yard, and in the state of whole or squared timber. The operations it undergoes from this period to its final employment in a building may be classed under two general heads, those which relate to individual pieces, and those which relate to their connexion with others. Under the first head are the operations of the pit saw, too generally known to need description, by which the whole timber is divided and reduced to the required *scantlings*; this term, from the French, *echantillon*, means dimensions, relative to breadth and thickness without respecting length:—Planing, which is giving a smooth face to wood by means of a familiar instrument called a plane, consisting of a chisel fixed in a frame, serving as a handle, by which the workman moves it along over the surface of the timber, shaving off its inequalities; timber thus prepared is said to be wrought:—Mouldings of various forms, and performed with particular planes or chisels:—Rebating, which consists in diminishing the width of a square, or rectangular piece of timber, for a certain depth on one edge, thus taking off a rectangle of the whole width, and less than the depth of the original piece; this

method is particularly used in door-cases, and the frames of casement windows, the *rebate* forming a kind of ledge for the door or casement to stop against:—Grooving or plowing, in which a narrow channel is excavated out of the thickness of the timber: the groove is either square, forming an equal section in the whole depth, or wider at bottom than at top, which is called a *dovetail* groove. Timber may also be *sunk* where the piece is formed like a wedge, or rounded; or *bevelled* in various shapes, which means when the section forms a figure without right angles.

We now come to the second and most important head of the operations by which timbers are connected together. These are generally speaking, by *mortise* and *tenon*, the first an excavation, and the second a projection, adapted to it; or by wooden pins or nails, spikes, screws, bolts, straps, and other fastenings of metal, or by glue, though this last is scarcely used except in joinery.

The following is a description of the most general and useful methods of joining timbers. First, by simple tenon and mortise, as when joists are framed into trimmers, the most usual method is to make the tenons in the middle of the breadth of the trimmer with a plain shoulder; see *fig. 1. Plate LXII. of Architecture*, which represents a section of the trimmer, and a part of the joist, framed in a longitudinal direction. But when binding-joists are framed into girders, as the binding-joist has to support the bridging-joists, and these the floor, the best method, in order to give strength to the tenon, is to make a rest of a short length under the tenon, with a sloping shoulder above, extending in a line from the extremity of the rest to the perpendicular of the square shoulder below at the upper edge of the binding joist. See *fig. 2. Plate LXII. of Architecture*. No. 1. represents a section of the girder through the mortises; Nos. 2 and 3 part of the joists in a longitudinal direction.

When a piece of timber is to be framed between two parallel pieces which are quite immoveable, the true method, in order to make close work, is to make the extremity of the tenon and the bottom of the mortise, at one end, in the arch of a circle, having its centre in one edge of the mortise, and the extremity of the tenon, and the bottom of the mortise at the other end, in a concentric arch from the same centre. As the mortise at this end must be much longer than the breadth of the tenon, there will be a large part of the mortise still open, which may afterwards be filled up. Instead of the bottom of the mortise here being formed in the arch of a circle, it may be cut quite parallel to the edge to the deepest part, as it will not impede the transverse piece in going to its place. This mode of framing is much used in ceiling, joisting for double floors: the long mortises cut in this manner are called *chase* mortises. In forming the tenon and mortise, at the end where the centre is placed, it is not necessary that the mortise and tenon should be so deep as to form an entire quadrant; in this case the bottom may be quite parallel, and only the further edge opposite the centre made circular. *Fig. 3. Plate LXII. of Architecture* represents a piece of framing, in the manner above described, A B, the bottom of the mortise, and the extremity of the tenon described from the centre C; D E the running, or chased mortise, which must be quite free from the circumference described by the point D, whether the extremity be in the circumference, or in a tangent, D F, parallel to G E.

The manner of representing the tenon and mortise at the end on which the centre is placed, when the mortise is made of a less depth than the breadth of the tenon, is shewn at the other end.

When a transverse piece is to be framed between two pa-

parallel joists, of which their vertical surfaces are oblique to each other, the upper edge of the transverse piece is turned downwards upon the top of the joists, and marked at the interval or clear; it is then turned upwards into the position in which it is to be placed, the mark at one end is brought into a right line with the vertical surface of the joist, and a line is drawn by the edge of a rule or straight edge placed vertically in the plane of the joist and the transverse piece; this line marks the shoulder of the tenon. The other end is drawn in the same manner. This mode of framing a transverse joist between two parallel joists is called by workmen tumbling-in-joists. The manner of tumbling in a joist is exhibited at *fig. 4. Plate LXII. of Architecture*. A and B are sections of the parallel joists, C D E F the transverse joist, or the piece tumbled in, G H the straight edge placed for drawing the shoulder C F.

A piece of timber may be joined at right angles to another in the manner of *fig. 3. Plate LXI. of Architecture*, which is a longitudinal section in the direction of the fibres of both pieces. A mortise is cut in the one piece to the breadth of the piece which is to form the perpendicular; the edge of the tenon is cut with a dove-tail notch, so that the piece may be at right angles to the other, and a wedge or key is driven from the other edge of the tenon, which forces it quite close. One inconvenience arising from the dove-tail is, that if the timber of which it is made be not quite dry, the tenon will shrink in proportion to its breadth, and therefore the perpendicular piece will be liable to be drawn to a certain degree. To remedy this defect, instead of the edge of the tenon being cut dove-tail ways, it may be notched, as is to be seen in *fig. 4. No. 1.* No. 2. shews another view of the perpendicular piece with the wedge.

Another method of fixing one piece of timber perpendicular to another, is to mortise the piece forming the base not quite through, enlarging the edges towards the bottom, and making the tenon of the perpendicular piece to fit the upper part of the mortise. Two wedges are then fixed to the bottom of the tenon; where the perpendicular piece is driven, the wedges will be resisted by the bottom, which will split the ends of the tenon, and fill up the mortise to the breadth at the widest place. This mode of fixing one piece at right angles to another is called fox-tail wedging. By this method, so long as the wedges are kept from slipping, the one piece can never be drawn from the other, without breaking the tenon. In order to enlarge the tenon in breadth still more towards its extremity, two other smaller wedges may be put in, of which their ends do not reach quite so far as those of the other two, which, when partly driven, the small wedges will then begin to widen the end of the tenon likewise, and make it fill the mortise completely at the bottom. *Fig. 5. No. 1.* shews the edge of the piece on which the mortise is cut. Fox-tail wedging is chiefly used where the pieces to be put together are small, and then the wedges are frequently driven in with glue; when the pieces to be joined are large, the former method is generally practised.

The fixing beams to wall-plates is called cocking or cogging. When a beam is to connect two wall-plates, in order to bind the sides of the building together, one method is to cut the end of the beam in the form of a dove-tail, and to make a corresponding notch in the wall-plate to receive it, as is shewn in *fig. 6. No. 1.* No. 2. is a transverse section at the neck of the dove-tail. *Fig. 7.* shews the same thing, with a small variation in the form of the dove-tail, fitted obliquely to the other piece. But when the timber has not been sufficiently seasoned, and when it begins to dry, the perpendicular piece may easily be drawn from the other, to a certain degree. Therefore, if the sides of the building are affected

by lateral pressure, this mode of fixing the one piece to the other will not prevent the walls from coming nearer together, or expanding. The most effectual method of preventing this is shewn at *fig. 8. No. 1.* where a small notch is cut out of the beam, and the contrary parts, viz. a double notch, cut in the wall-plate to receive it. No. 1. the beam shewn longitudinally upon a transverse section of the wall-plate; No. 2. the upper face of the wall-plate. The best method of connecting any number of posts with cross-beams depends upon this principle. *Fig. 9. No. 1.* shews a transverse section of a post with two beams longitudinally fitted to it, in the manner of cogging beams to wall-plates; No. 2. a part of one of the beams, shewing the notches. The strongest method of fixing the purlins of a roof to the rafters also depends upon the same principle. *Fig. 10. No. 1.* is a section of the rafter, with the purlin longitudinally drawn; No. 2. the upper edge of the rafter; No. 3. the under side of the purlin, shewing the notch.

The method of joining timber laterally, by means of keys and dove-tails, is ingenious, and not generally known; it will be necessary to exhibit and describe the manner of doing it. *Fig. 1. Plate LXI. of Architecture, No. 1.* is a longitudinal section of two pieces joined in this manner, with the dove-tail pieces and the wedge or key, by means of which they are forced against the ends of the pieces to be fixed, and in order to make the one press harder to the other, the interior angle of the dove-tails is greater than the exterior one, formed upon the pieces to be joined; No. 2. is a transverse view of the mortise, exhibiting the ends of the dove-tails and keys. *Fig. 2.* is the same method, applied in joining parallel pieces not touching each other together, which is plain to inspection.

The modes in which beams are lengthened are of infinite variety; some of the most approved forms are as follow. A beam may be continued to any extension by building it in three thicknesses; see *fig. 1. Plate LX. of Architecture*. It may also be done by splicing one to the end of another, called by carpenters scarfing, which is of various forms, as in *figures 1, 2, 3, 4, 5, 6, 7, and 8.* When a beam is to be lengthened, as in *fig. 2. and 3.* it is very difficult to get the joints close when the pieces composing it are very large, and hence they are seldom used but for very small pieces, which may be glued together. To remedy this inconvenience in large works, as well as to make it less dependent on the bolts; and to prevent every possibility of the one being drawn away from the other, is to indent them together, called tabling, as in *figures 4, 5, 6, 7, 8, and 9,* and to leave a small space at the end or meeting of each table for a wedge. In the operation of joining timbers in this manner, the pieces are laid so as to bring the joint as close as possible, the wedge is then driven while another person strikes the extremity of one of the pieces with a large hammer or mallet, which will bring the joint quite close, if they have been well fitted together previously to the operation; of these two forms, *figures 5, 6, and 7* ought to have the preference, as the faces of the tables are parallel to the fibres of the wood, which will make them resist any longitudinal strain with a much greater force; but as a disadvantage arises from this form, that more than half the wood is cut quite through at the two ends of the joints, it has been found necessary to fix plates of iron across them, as are shewn. However, there is less to be apprehended from the tearing of the fibres, by being drawn in a direction of their length, than from the bending of the bolts.

Fig. 6. is a scarf with several tablings; in this it is to be observed, that the wedges in the two extreme mortises are only effective. A wedge in the middle would tend to force the joints open, and therefore the other two should only be

fixed. Long scarfings add to the strength; but to increase the number of tables more than two, is, it is thought, rather disadvantageous, as it shortens its fibres, and consequently makes their resistance less. *Fig. 7.* is an excellent method of scarfing in two pieces, each piece being tabled together, as in *fig. 5.* It has been thought by some that tabled scarfings lessen the section of resistance more than is necessary; and for this purpose they prefer *fig. 8.* with an oblique scarf, where the keys are let half into the one and half into the other: but in this mode, as a draught must be left for the keys, they will be apt to be turned round in the driving, and therefore will have less effect in keeping the pieces together. *Fig. 9.* is a mode of scarfing a beam by tabling the pieces together; No. 1. and 2. are the two halves; when bolted together they have the appearance of being quite straight, as is shewn in No. 6. The tables are made in the form of obtuse angles, with a ridge in the middle, depressed and raised alternately, in the form of re-entering and salient angles; No. 3. section across the depressed part; No. 4. section across the raised part; No. 5. section of the beam when bolted together. In all forms of scarfing whatever, every butting joint should be strapped across with iron on both sides; this will in a great degree prevent the bolts from being bent, and will increase the longitudinal resistance at the weakest section. If a beam is to be scarfed and tabled as in this last mode, the utmost care ought to be taken in the workmanship, so that all the butting-places ought to be closely fitted together.

Connected with scarfing is the method of joining timbers, which may either be endways, sideways, perpendicularly, or obliquely. When two pieces of timber are so joined that the common seam or joint is perpendicular to the fibres of both pieces, then the joint is said to be butting, and is called by workmen a butting or heading joint. When two pieces of timber are joined together, so that the common seam is parallel to the fibres of both pieces, this then may be called lateral or longitudinal joining, and the joint may be called a longitudinal joint, as it runs in the direction of the grain; and when the fibres and seam of the one piece run perpendicular to the fibres of the other, this mode of joining timbers may then be called transverse joining, and the joint may be called a transverse or perpendicular joint. Lastly, when the fibres of the one piece run obliquely to those of the other, this is called oblique joining, and the joint is called an oblique joint.

Butting joints for many purposes are preferable to scarfings, particularly in small work, such as the hand-rails of stairs.

They are fixed together with bolts, having a screwed nut at each end, the head of one of these nuts must be quite round and the other square; the round one must be cut in its circumference full of notches. After having let in the bolt perpendicularly to the joint in both pieces, the nuts are sunk from one side across the grain, until the ends of the bolt may be able to pass the interior screw made on purpose to receive the exterior one; the square nut is first put in and the one end of the bolt is firmly driven into the bore made on purpose to receive it, and screwed to the nut. The other notched nut is then put in, and the bolt in its place; the one piece may be turned round upon the other until the joint is close, but in order to secure the joint from turning round, two dowels may be inserted on each side of the bolt. Drive the one piece as close to the other as the nut will permit. Then by means of a narrow pointed screw-driver and mallet, the nut may be turned round until the joint is quite close.

Fig. 5. Plate LXII. of Architecture represents the meeting

of a pair of rafters and the king-post, together with the manner of strapping them. This mode of forming a junction by making the rafters meet each other, without the intervention of the joggle-head, which is generally made to the king-post, has the advantage over the common mode with a joggle-head, exhibited in *fig. 6. Plate LXII. of Architecture*, as the shrinking of the king-post at the joggle will allow the roof to descend, and consequently put it out of shape.

One method of strapping the tie-beam to the king-post is exhibited at *fig. 7. Plate LXII. of Architecture*. The mortise of the strap on both sides is made oblong, and that through the king-post is made somewhat lower, in order to give the wedges a proper draught. An idea may be formed by examining No. 1. which represents the bottom of the king-post with part of the tie-beam; No. 2. is a longitudinal section of the king-post, with a transverse section of the beam, in the upper part of this is shewn the manner of fixing the wedges, with the form of the washers, which are necessary in preventing the strap on each side from penetrating into the wood, the whole force of the friction being taken away from the straps by them. Another mode of fixing the tie-beam to the king-post is by a bolt, as exhibited at *fig. 8. Plate LXII. of Architecture*. No. 1. shews the elevation of the bottom of the king-post; No. 2. is a vertical section cutting the beam transversely; in order to give greater security, there are two nuts, one let in from the face of the beam and the other from the edge. *Fig. 1. Plate LXIII. of Architecture* shews the meeting of a brace and straining-piece under a truss beam, as the brace may be resolved into two forces, one pushing in a direction of the beam, that is, compressing the straining-piece, and the other tending to break it transversely, the end of the brace is cut in the form of a Sally, or bird's mouth, as it is called by workmen. Another method is shewn at *fig. 2. Plate LXIII. of Architecture*. This mode is used in the roof of Greenwich chapel. See the figures in the article ROOF. It may, however, be observed, that this abutment is not of the best kind; the space left for the brace to give pressure to the straining-piece is much too small; the upper part should not be let into the straining or truss-beam, this prevents the straining piece from acting with its full force, and weakens the truss-beam.

Fig. 3. Plate LXIII. of Architecture shews the method of securing a collar-beam, at one extremity, to its adjacent rafter, in order to prevent its being pulled away at the joint, a bolt is made to pass through the rafter at the angle of their meeting.

Besides what has already been shewn of the hanging of king-posts to their principal rafters, *fig. 4. Plate LXIII. of Architecture* is another. The rafters meet each other as in *fig. 5. Plate LXII. of Architecture*, but instead of the forked strap, a bolt is here used, with a spreading head, so as to form a shoulder at right angles to the rafters, which are notched, in order to receive the bolt. This also prevents the rafters of a roof from sinking in the middle. Instead of any part being of wood, the whole may be of iron, consisting of two parts, connected together by means of a screw, which will draw the tie-beam higher and higher at pleasure as it is turned round. No. 1. part of the king-post with the bolt; Nos. 2. and 3. part of the rafters; No. 4. view of the upper edge of the rafters. Various forms are sometimes adopted for the abutments at the bottom of the king-post; for the braces, when the king-post is not sufficiently broad at the bottom, as to allow the abutting shoulder to be at right angles to the length of the brace, and to its whole breadth. Two of the most approved forms are exhibited in *figures 5. and 6. Plate LXIII. of Architecture*. *Fig. 5.* shews the form of the abutment, when the part which makes the resistance

in the direction of the king-post is at right angles to it. *Fig. 6.* shews the form of the abutment, when the part of the shoulders which makes the resistance is at right angles to the brace; this mode is better than the former, because it is less liable to compress the king-post at the bottom.

Fig. 7. Plate LXIII. of Architecture represents one form of the heel of a principal rafter, with the socket cut in the end of the tie-beam to receive it; but as the small part cut across the fibres of the beam is so near to the extremity, and as this part sustains the whole force of the rafters, in drawing the beam in a direction of its length, it will be liable to be forced away. To prevent this in some measure, a double resistance is formed, as in *fig. 8. Plate LXIII. of Architecture*, equally deep into the beam; this mode gives the strength of the intermediate part contained between the two abutments, in addition to the end resistance, which is of itself equally strong with that represented in *fig. 7.* The intermediate part in this mode being cut across the fibres, it is easily split away. A more effectual method of forming a double resistance is shewn at *fig. 9. Plate LXIII. of Architecture*, where the heel of the rafter and the socket is cut parallel to the fibres of the beam; the tenon forms the second abutment, being removed farther from the extremity. No. 1. the elevation of part of the rafter with part of the beam; No. 2. the upper edge of the beam, shewing the mortise. But the most effectual mode of forming a resistance on the heel of the rafter and socket on the extremity of the beam is that represented by *fig. 10. Plate LXIII. of Architecture*, where the abutment is brought nearer to the inner part of the heel, which leaves a greater length on the end of the beam, in order that the resistance may still be greater than what is given by the wood. A strap may be placed round the extremity of the rafter, and the two ends bolted together through the beam, as is shewn by this diagram at No. 1. and 2.

Fig. 11. Plate LXIII. Architecture represents two braces of a roof meeting an iron king-post, which is only a small rod of iron sufficiently strong to hang up the middle of the beam, and to receive the force of the braces by the weight of the middle rafters. The strap which prevents the braces from being pushed downwards, has an eye through each side, and the bottom of the king-rod is formed with a cross equal in length to the thickness of the braces; this cross is perforated in its length to receive the bolt.

The purposes for which wood is employed in modern buildings, and particularly in those of England, are very various. It is used to form the frame work of the roof, and in laths or boarding, to support the covering of tiles, slates, &c. Long pieces, called *bond* or *chain* timber, are laid in the walls to strengthen and bind them together: other flat pieces, called *plates* or *wall plates*, are placed to receive the ends of the girders, joists, and other timbers, which form the framing of the floors, and afford them a level bed. *Ties* are placed across the building to assist in keeping the opposite walls in their situation, and counteract the lateral pressure of the roof, and diagonal ties at the angles. *Lintels* are laid over the apertures of doors or windows to support the incumbent walls. The floors are framed with various beams and joists. The rooms are divided with *quarter partitions*, being a frame work of small posts and horizontal and

diagonal pieces placed at about a foot asunder, and destined to be cased with lath and plaster on the outside. Door and window-frames are also placed in the apertures of the walls. In bad foundations piles are sometimes used; and sometimes planking, and what are called *sleepers*, pieces of timber, laid at short intervals transversely, beneath the foundation wall, and extending about two feet wider: besides all the finishing wood work, such as doors, windows, wainscoting, &c. which belongs to joinery. Carpentry is also employed to construct the centres for arching and vaulting, and frequently in entire bridges. Cofferdams, caissons, flood-gates, and all the methods of building in water, derive large assistance from this art.

The general principles of measuring and valuing carpenter's work may be given very shortly; and to enter into minutiae would be superfluous in the present work. The timber used for building in London, and in the greatest part of England, consists entirely of oak and fir; the first the growth of this country, the second imported chiefly from Norway. That timber which is out of sight, as being covered with lath and plaster or other facing at the completion of the building, which is by much the greater part, is used as it comes from the saw, without the operations of the plane. Of this, part is framed as the roof, floors, partitions. The quantity is measured by the cubic foot, and either valued as *fir framed*; or else the quantity of timber being ascertained, is put down as *fir without labour*, (*fir no labour*) in the valuation of which is included the original price of the timber, with the expence of cartage, sawing, waste, and the profit to the carpenter; and a superficial dimension is taken of the frame or space in which the timber was employed under the denomination of *labour* and *nails*, to a floor of such a kind, roof, quarter partition, &c. in which is estimated the value of the workmanship, with the master's profit. The choice between these two methods is influenced by custom, and the convenience of the measurer. The timber used in the walls, as the plates, and bond timber, is measured separately by the cubic foot, and put down under the denomination of *fir in bond*: this is valued at a medium price between *fir framed*, and *fir without labour*. As for the timber which remains apparent after the completion of the building, it is generally worked in some manner with the plane, and is measured by the cubic foot, and denominated and valued according to the workmanship; thus a doorcase is *framed, wrought, rebated, and beaded*. We have mentioned only *fir* because it is infinitely more used than oak, however the latter is measured in the same way.

Boarding, such as weather-boarding, boarding for slates, &c. is measured by the superficial foot, and valued in the bill by the square, or 100 superficial feet. Timber used in very small scantlings, as fillets, is valued, not by the cubic or superficial foot, but by the foot in length, called *foot run*.

Having thus described what is properly included under the general head of carpentry, the reader is referred, for more particular information, to the articles *CENTRE, FLOOR, and ROOF*; under which articles that part of constructive carpentry which depends on certain branches of mechanics and geometry will be fully explained.

Cart

CART, a vehicle mounted on two wheels, drawn by horses, used for the carriage of heavy goods. The word seems formed from the French *charette*, which signifies the same; or rather the Latin *caretta*, a diminutive of *carrus*. See **CARR**.

Mr. Sharp's *rolling cart* is fixed upon two rollers, running a-breast, or parallel with each other, and both placed under the body of the cart, working upon pivots like the wheel of a wheel-barrow. The rollers are both cylinders of cast iron, two feet diameter, and sixteen inches broad. An iron spindle passes through the centre of each roller, upon the ends of which rest the four planks that support the body of the cart. Criminals are drawn to execution on a cart. Bawds, and other malefactors, are whipped at the cart's tail.

Scripture makes mention of a sort of carts or drags, used by the Jews to do the office of threshing. They were supported on low thick wheels, bound with iron, which were rolled up and down on the sheaves to break them, and force out the corn. Norden and Niebuhr, in their "Travels," inform us, that this method of threshing is still practised in Egypt and Arabia. The former says that in Egypt they thresh, or rather tread, rice by means of a sledge drawn by two oxen, and that the man who drives them is upon his knees, whilst another has the care of drawing back the straw, and of separating it from the grain that remains underneath. In order to tread the rice they lay it on the ground in a ring, so as to leave a void circle in the middle. The Arabians, says the latter writer, in threshing their corn, lay the sheaves down in a certain order, and then lead over them two oxen, dragging a large stone. They use oxen in Egypt, he adds, as the ancients did, to beat out their corn by trampling upon the sheaves, and dragging after them a clumsy machine. This machine is not, as in Arabia, a stone cylinder; nor a plank with sharp stones, as in Syria; but a sort of sledge, consisting of three rollers, fitted with irons which turn upon axles. A farmer chooses out a level spot in his fields, and has his corn carried thither in sheaves upon asses or dromedaries: two oxen are then yoked in a line; a driver gets upon it, and drives them backwards and forwards, or rather in a circle upon the sheaves, and fresh oxen succeed in the yoke from time to time. By this operation, the chaff is very much cut down: the whole is then winnowed, and the pure grain thus separated. Something of the like kind also obtained among the Romans, under the denomination of *plaustra*, of which Virgil makes mention. Georg. I.

*Turdaque Elusina matris volventia plaustra,
Tribulaque, trabeaque—*

On which Servius observes, that *trabea* denotes a cart without wheels, and *tribula* a sort of cart armed on all sides with teeth, used chiefly in Africa, for thrashing corn. The Septuagint and St. Jerom represent these carts as furnished with saws, inasmuch that their surface was beset with teeth. David having taken Rabbah, the capital of the

Ammonites, ordered all the inhabitants to be crushed to pieces under such carts, moving on wheels set with iron teeth; and the king of Damascus is said to have treated Israelites in the land of Gilead in the same manner. 2 Sam. xii. 31. Amos. i. 3. Calm. Dict. Bibl. tom. 1. p. 366.

CART, in *Agriculture*, is a carriage or vehicle constructed with two or more wheels, and drawn by one or more horses. It is employed for the purpose of conveying manure, hay, grain, and various other articles which are connected with the farm. Carts are made of different forms and dimensions, in some districts according to the nature of the materials they are intended to carry, and the uses to which they are applied; but by suitable contrivances they may be easily constructed, so as for the same cart to serve different uses. In the more southern parts of the kingdom this is mostly the case, by which there is not only a considerable saving, in fewer carts being wanted, but likewise in less room being taken up by them in the sheds or houses where they are kept. In these situations they are mostly formed in a close manner, having ladders or other similar contrivances applied when they are wanted to convey any of the more bulky sorts of materials, such as hay, straw, &c.

It is obvious that the chief object in the construction of carts should be to adapt the wheels and axle in such a manner, that the power may be applied in the most favourable direction for draught, and that the carriage may move with the least possible force. In this view the height of the wheels should likewise be well adapted to that of the animals which are employed in drawing them; but the exact heights which are the most favourable under different circumstances have not yet been fully shewn by any trials that can be fully depended upon. There is likewise another point which ought to be particularly considered in the making of farm-carts, which is, that they are not more heavy than is necessary; which is too often the case in the southern parts of the island. It has been remarked that the large heavy carts and waggons, which are so common in the southern districts, are not only reprobated, but almost wholly in disuse in those of the north, where small carts are in general use. Though there cannot be any doubt but that carts must vary in their forms, sizes, and modes of construction, according to the nature and situation of the roads, and many other local circumstances; yet for the purposes of farming, especially in field work, probably those of the light, single, and two horse kind may in general be the most advantageous, convenient, and useful.

It has been observed, in the twenty-seventh volume of the Annals of Agriculture, by lord Robert Seymour, that "the advantages of single-horse carts are, he believes, universally admitted, wherever they have been attentively compared with carriages of any other description. By his own observation he is led to think that a horse, when he acts singly, will do half as much more work as when he acts in conjunction with another; that is to say, that two horses will,

separately, do as much work as three conjunctively: this arises, he believes, in the first place, from the single horse being so near the load he draws; and, in the next place, from the point or line of draught being so much below his breast, it being usual to make the wheels of single horse carts very low. A horse harnessed singly has nothing but his load to contend with, whereas when he draws in conjunction with another, he is generally embarrassed by some difference of rate, the horse behind or before him being quicker or slower than himself; he is likewise frequently inconvenienced by the greater or lesser height of his neighbour: these considerations give, he conceives, a decided advantage to the sort of cart he is recommending." If any other is wanted, that "of the very great ease with which a low cart is filled may, he says, be added: as a man may load it, with the help of a long handled shovel or fork, by means of his hands only; whereas, in order to fill a higher cart, not only the man's back, but his arms and whole person must be exerted." To the use of single horses in draught he has heard no objection, unless it be the supposed necessity of additional drivers created by it: the fact however is, that it has no such effect; for, horses once in the habit of going singly, will follow each other as uniformly and as steadily as they do when harnessed together; and accordingly we see, says he, "on the most frequented roads in Ireland, men conducting three, four, or five, single horse cars each, without any inconvenience to the passenger: such likewise, is the case in this country, in which lime and coal are generally carried upon pack-horses, where one man manages two or three, and sometimes more." And in a preceding volume of the same work, Mr. Young is decidedly of the same opinion, which he clearly shews to be founded in truth, by entering into a variety of discussion in respect to the points in which they are preferable to tumbrils or waggons. In the northern districts they usually draw in these carts from twelve to twenty-four hundred weight, and where the roads are good, occasionally thirty, with much ease and facility.

And Mr. Donaldson, in his view of the "Present State of Husbandry in Great Britain," seems to think that, "for carrying on the ordinary operations of husbandry, carts drawn by two horses are greatly superior to large, cumbersome, unwieldy waggons, that require four, five, or six horses to move them along. It has of late," says he, "been a subject pretty much agitated, whether single-horse carts are not to as great a degree superior to those drawn by two horses, as these have been represented to be to waggons. Single-horse carts are certainly loaded and unloaded with much less trouble, and are in every way more easily managed, especially when carrying out dung, or when used for doing any odd jobs on a farm." It has also been found, from long experience and the most attentive observation, that "one horse will draw, on any road, two-thirds of the load that two horses, drawing in a line, and of equal power, are capable of doing. The carters of the town of Falkirk, in Stirlingshire, for example, have long been famous for the great weights drawn by their carts. Before the navigable canal between the Forth and Clyde was made, the whole goods transported to and from Glasgow, and the ports upon the Forth, were," says he, "drawn upon one and two-horse carts belonging to these carters; the most expert of whom have long given the preference to carts drawn by one horse, as they experience no difficulty in carrying upon a cart, drawn by a single horse, from Borrowstounness to Glasgow, a distance of upwards of thirty miles, and of indifferent road, from twenty to thirty-five hundred weight." It is, he observes, further worthy of remark, that "at the great iron-

work at Carron, the company engaged in it formerly made use of waggons and waggon-ways, to wheel their coals and other heavy articles upon: but have entirely laid aside the use of them, and on principles of economy, employed carters with single-horse carts to transport the heavy articles which they require."

In the agricultural report of Northumberland it is likewise remarked, that "single-horse carts are becoming more prevalent in several parts of that county; and that Mr. James Johnson, a common carrier at Hexham, has a horse, sixteen hands high, that commonly carries from Hexham to Newcastle 24 cwt., and 20 cwt. back again; and there are instances of his having carried 26 cwt. from Newcastle to Hexham, which is a very banky, heavy-pulling road." It is also further noticed that "the neatest, most useful, and best contrived carts we know, are those made in many parts of the North-Riding of Yorkshire. The single-horse carts of this construction, used for carrying coals from the county of Durham into Yorkshire, are 60 inches long, 36 inches wide, and 18 deep, hold 24 bushels of coals, when set round the sides with large ones and upheaped. A man, or boy, drives three of these, two of which are equal to the greatest quantity ever carried by three horses." Mr. Charge of Newton, sends three of these carts for coals every day, which bring 72 bushels, the distance of 26 miles, there and back, which is performed in 12 hours by one man. The same gentleman's two-horse carts bring 36 bushels of the same coals.

And in the agricultural survey of Cumberland, the writers say, "the advantages of single-horse carts are so well understood in this county, that we did not see any other used. Three single-horse carts are driven without any difficulty, by a man, or boy, or even women and girls."

The author of the Agricultural Report of Mid Lothian, states, that "the wheel-carriages employed in husbandry are only the close-cart and the corn-cart, both of a light construction, drawn by two horses, and of late by one. The large wains, or heavy four-horse waggons, employed in English husbandry, are discarded there. Two horses in a cart are commonly loaded with 18 or 20 cwt. One horse draws still more easily 12 cwt.; even 24 cwt. is frequently put on a single horse; and 30 cwt. on good roads is not uncommon." And that "the first sort of cart has lately been much improved: when placed on its axle, the bottom at each side projects over the inner head of the naves as far as nearly to touch the spokes of the wheels; from which acquired breadth the capacity is enlarged; while the side-standards, being brought nearer to a perpendicular, are able to sustain more weight." The dimensions are, the length five feet three inches; the breadth below, four feet; the breadth above, four feet three inches; the depth, one foot three inches; containing about a cubic yard. The price of a cart, painted, 11. 15s. not including wheels, axle, or mounting, which may amount in all to seven or eight pounds more. The wheels are generally 52 inches high, the axle commonly of iron, from an idea, that, in the end, it is more economical to have them so: for it is not found in practice that iron axles are either more or less difficult to draw, although not half the thickness, of those of wood."

It has been suggested on the ground of much experience, that, in constructing carts of this sort, the capacity of waggons is by no means an accurate rule to proceed by; as on finding that they contained in the bed, or *back*, ninety-six cubical feet, being twelve feet long, four feet wide, and two feet in depth; it was supposed that to give one horse the fourth part of the load of four, it would only be necessary to let the cart have the space of twenty-four cubical feet, or

to make it four feet by three, with the depth of two; but from the vast superiority of horses working singly, over those in teams, it was soon discovered, that they required to be very considerably enlarged, admitting of having the dimensions of five feet one inch in length of bed or *buck*, three feet seven inches in breadth, with two feet in depth; so as to contain thirty-five cubical feet and a fraction. This, therefore, affords a further striking proof of the great superiority these small carts have over those of the large kind, in the quantity of work which they are capable of performing.

In speaking of the advantage of having low cast-iron wheels, it is remarked by lord Seymour, in the paper just mentioned, that "the price of iron, cast into wheels, is 16s. per cwt., and the weight of each wheel about three quarters of a cwt. Two inconveniences only, he believes, have been found from the use of low cast iron wheels: the first is, that cast-iron is very liable to breakage, upon concussion; the next is, that the course of so small a diameter creates a very quick consumption of grease. The first of these objections is in a degree removed by the ease with which the rim of the wheel is repaired by the application of worked iron, which being joined to it by a rivet, the wheel acquires some little elasticity, and thereby becomes perhaps stronger than when it was new. In order that the supply of grease may keep pace with the consumption, he has introduced four grooves, or cavities, in the boxes, increasing a little towards their centres; and in order to defend the axle-tree, which consists of worked iron, against the harder body of the box, he has steeled the extremity of it."

These small carts are considered by many, from actual experience, to be better adapted to the carrying of all sorts of materials except those of the very bulky kinds, and such as trees, blocks of stones, &c. the weights of which might injure them, and which cannot from their nature admit of division. In all hilly districts where the roads are of an inferior kind, and the inhabitants poor, these are the carts that are in most general use, and which are found the most advantageous. The superior goodness of the roads in some of the northern parts of the kingdom have likewise been ascribed to the use of these kinds of carts, as large carriages of all sorts that require the wheels to be locked in descending hills, are the destruction of roads.

By the author of the New Farmer's Calendar it is stated that "of the great saving to be made by one-horse carts there can be no doubt, since it has been experimentally proved, and was moreover, easily to be discovered from just theory. More weight may be drawn by six horses in so many carts, than by eight in a large waggon; and one man may manage two carts in the country." There are, however, he thinks, "some peculiar inconveniences attendant upon this plan, which are sufficiently obvious; and, says he, notwithstanding it has been, for years past, so warmly recommended by very powerful pens, it never has, nor probably ever will be, relished by the generality of farmers."

After this view of the nature of carts in general, and of the particular advantages of single-horse carts; it may be useful to describe the different sorts of carts that are employed in the business of husbandry.

Close cart, a name given to all such carts as have no ladders, rails, or wings, attached to them. They are made close by boards, and mostly employed in conveying dung, gravel, earth, or such other materials as have considerable weight, in a small compass. By the application of wings or ladders to them, they are however, frequently made to serve the double purpose of conveying heavy close matters as well as those of a light bulky nature. This sort of cart is represented at fig. 3. Plate III. of *Agriculture*.

Corn cart, is that sort of cart which is only placed occasionally on wheels, for carrying hay, corn in the straw, or other light bulky articles; carts of this kind are generally composed of standard rods, and spars, without deals, but broader and much longer than the close cart, that they may hold a more bulky load. They cost from 20s. to 30s. in Scotland, but in England they are considerably higher. They are commonly employed in the northern parts of the kingdom for carrying hay, grain in the straw, and other similar bulky materials. A cart of this sort is shewn at fig. 4. Plate III.

Coup cart, a cart of the close kind, so denominated from the body-part resting on a sort of frame, to which it is kept by means of staples, or other contrivances, through which a cast-bar, or wooden pin, is put, by which it is confined, and which can be readily removed when the load is to be either partially or wholly discharged. Carts of this sort are generally used in putting dung upon land, and are convenient for many other purposes in husbandry. See fig. 3. Plate III.

Drag cart, a sort of cart invented by lord Sommerville, which is constructed with a drag, or some other contrivance, for checking, or regulating the rapidity of the motion in going down hills, or other declivities. A full account of this cart has been given in the second volume of "Communications to the Board of Agriculture." At fig. 5. in Plate III. is a perspective view of a cart of this sort to be drawn by two strong oxen, by a pole, yoke, and bows, made to carry 45 cwt. In the front of this figure is represented the method which his lordship has contrived for adjusting the position of the centre of gravity of the load, to prevent its pressing too much on the cattle in going down hill, the front of the cart being elevated by means of a toothed rack screwed to the front of the cart, and worked by a pinion, and the handle, *a*, immediately connected with the pole, *c*. By means of this pinion and rack, the front of the carriage is elevated more or less, in proportion to the declivity of the hill, by which means the weight of the load is made to bear more on the axis, and less on the necks of the oxen.—On the side view of this cart is represented the manner of applying the friction-drag, which is made to press more or less on the side of the wheel, according to the steepness of the descent:—*bb* is the friction-bar, or drag, the one end of which is connected with the tail of the cart by a small chain, and the other end to the front, by means of a toothed rack, *bd*, which catches on a staple in the front of the cart, by which the friction-bar may be made to press on the side of the wheel, more or less, at the discretion of the driver: the notches or teeth in this rack, it is observed, should be as close to each other as circumstances will permit. And in this representation, the friction-bar is, he remarks, applied lower upon the wheel than was at first proposed, in order to divide the pressure and friction more equally on the opposite sides of the wheel, so that the pressure on each is diminished, the risk of over-heating and destroying the friction-bars is also rendered less, than if the whole pressure was applied in one point on the top of the wheel. The weight of the iron-work of this cart is 2 cwt. 20 lb. This is unquestionably an useful contrivance for hilly districts. At fig. 5. in the same Plate, is a side view of a cart of this kind of a smaller size, to carry 25 cwt. and to be drawn by steers, or small oxen, with the friction-drag, *bb*, out of use; and representing another and more simple method of adjusting the centre of gravity of the load to the declivity of the descent: *ab* is part of the arch of a circle, whose radius is nearly equal to its distance from the axis of the cart, and having several holes in it, through which a strong iron pin is put, to keep

the body of the cart at any desired inclination with the pole:—*c.*, a small chain to prevent the body of the cart being thrown too far back, through the carelessness of the driver in adjusting it:—*d.*, the upper stage of the cart, for carrying bulky loads.—The weight of iron in this cart is 1 cwt. 50 lb. This is a very useful, neat, light sort of cart for many purposes.

The advantages of the friction-drag, and other contrivances in this cart, according to the ingenious account of Mr. Cumming, contained in the same volume, are,

“1. The method, which is equally simple and expeditious, of adjusting the centre of gravity of the load, so as to have a proper bearing on the horses or cattle in going down hill, the advantage of which must be obvious to every man of science, more especially with bulky loads, in which the centre of gravity lies high.

2. The method of applying friction to the side of the wheel to regulate the motion of the carriage in going down hill (instead of locking the wheels), the advantages of which method appear to be as follow: namely, 1st. The pressure and degree of friction may with great expedition be adjusted to the steepness of the declivity, so that the carriage will neither press forward, nor require much exertion to make it follow the cattle. 2dly. The friction is so applied to the wheel, that a given pressure will have twice the effect in retarding the progress, that it would have if immediately applied to the body of the carriage, or to the axis: and by applying the friction on both sides of the wheel, the risk of heating and destroying the friction-bar is much less than if the same degree of friction was applied in one place. 3dly. This apparatus is so conveniently placed, that it can be instantly applied or adjusted, without stopping the carriage, or expelling the driver to the same danger as in locking a wheel. And, 4thly. This useful contrivance, in which he says simplicity and ingenuity are so happily blended, will assume yet greater importance when applied to both the hind wheels of waggons, by which means the resistance may always be proportioned to the steepness of the descent, the tearing up of the road prevented, the unnecessary exertion of the cattle in drawing the locked carriage down hill avoided, the danger to which the driver is sometimes exposed in locking the waggon wheel totally avoided, and the time now lost in locking and unlocking the wheel saved to the proprietor.” These are certainly advantages of much importance in many districts where the roads are hilly.

At *figs. 7 and 8* in the same *Plate* are views of carts to be drawn by a single horse, by shafts. By an attentive comparison of those drawn by shafts, with those that are drawn by the yoke and bows, the superiority of the pole to the shafts, and the advantage of making the cattle to draw by the yoke in preference to drawing by the forehead, become evident. When cattle draw by the shafts, says his lordship, the one before the other, it is impossible for the driver to know that each exerts an equal force, so as to contribute equally to the draught; but when they draw by the pole and yoke, the point of draught being in the middle of the yoke, when the beasts draw equally, the yoke will stand square with the pole, and the position of the yoke will always enable the driver to discover the defaulter, and to bring him to a proper exertion: it is, he says, this harmony of draught, and equality of exertion, that gives so great advantage to drawing by the yoke, that it is scarcely possible to say what weight of load two good large oxen can draw on a level road.” The powers of cattle drawing by the forehead, on lord Shannon’s estate, are recorded by Mr. Young and Mr. Billingsley:—an ox of the late

Mr. Tatterfall, near Ely, drew four tons of wood on a level surface without apparent difficulty. What then, says he, “might not be expected from the equal exertion of two such powerful animals, acting at the equal ends of the same yoke?” Notwithstanding these judicious observations, further trials are wanting with respect to the best modes of draught.

Hay Cart, a cart made use of for conveying hay from the field; it is constructed in the same way as that made use of for corn. See *Corn Cart*.

Quarry Cart, is a stiff, strong sort of cart, employed in quarries. Carts for this purpose are variously constructed, according to the nature of the materials to be conveyed by them. When flat stones of great length and breadth are to be carted, they should be low, for the convenience of loading and unloading, and at the same time very firmly put together.

It is stated in the Agricultural Survey of the County of Perth, that “Mr. Mylne, of Mylnfield, employs a cart of a particular construction in his quarry of Kingoodie, which merits the attention of those who have works of a similar nature. This cart has a bend in the axle, which brings it within fourteen inches of the ground, although moving on wheels more than five feet high. The ease with which it is drawn, loaded, and unloaded, is superior to the common cart, in the proportion of 7 to 3.” It is seen at *fig. 9.* in *Plate III.* He also uses in this quarry “a cart for carrying very large stones, such as mill-stones, &c. which is drawn as easily upon wheels of two feet two inches in height as upon wheels of a greater diameter. In this cart the axle is only about five feet long, so that the wheels run under the body of the frame, which is flat, and may be made of any breadth or length required.”

Single horse Cart, that light sort of cart in which only one horse is employed. The term is made use of to distinguish them from those of the large kind, in which three, four, or even a greater number of horses are made use of. Carts of this small construction are extremely useful for all the various little purposes of cartage about the farm, as has been fully shewn above. See *figs. 3. 7. and 8.* in *Plate III.*

Three wheel Cart, a kind of cart that is constructed with three wheels, one being commonly placed in the middle, before, and generally of a smaller size. Carts of this sort are mostly close, and used when great quantities of earth or other materials are to be conveyed at once to some distance.

CARTS, laws relating to. By 13 Geo. III. c. 78. no cart, having the sole or bottom of the fellys of the wheels of the breadth of nine inches, shall be drawn with more than five horses; and no cart, having the said sole the breadth of six inches, shall be drawn with more than four horses; and those of less breadth than six inches shall not be drawn with more than three horses, under a penalty on the owner of 5*l.*, and on the driver (not being the owner) of 10*s.* for every horse above the stipulated number: the information to be laid within three days and the action commenced within one calendar month after the offence committed. Exceptions are admitted in favour of carriages, moving upon wheels or rollers of the breadth of 16 inches on each side, with flat surfaces, and such as justices allow by licence to be drawn up steep hills, or on roads that are not turnpikes, or in deep snow or ice, or carrying any one stone, block of marble, cable rope, piece of metal, or ammunition and artillery for his majesty’s service. Two oxen or horned cattle are considered in the contemplation of this act, as one horse. Moreover it is enacted by 6 Geo. I. c. 6. that no person in London and Westminster, or within

10 miles, shall carry at one load in carts or waggons having their wheels shod with iron, more than 12 sacks of meal of five bushels each, nor more than 12 quarters of malt, nor more than 750 bricks, nor more than one chaldron of coals, on pain of forfeiting any one of the horses, with geers, bridles, &c. And by 18 Geo. II. c. 33. wheels of every cart, car, or dray, within the bills of mortality, shall be six inches broad in the felly, and not wrought about with iron, nor be drawn with more than three horses, after they are up the hills from the water-side, under a penalty of 40s.; but this act does not extend to any country cart or waggon, that shall bring any goods, or shall carry any goods half a mile beyond the paved streets of the said cities and places. Any person, within the said limits, using any cart, car, or dray, having the wheels full six inches broad, when worn, may have the same bound round with tire of iron, provided it be six inches broad, and made flat, and not set on with rose-headed nails. No person shall drive any cart, within the said limits, unless the name of the owner, and number of such cart, &c. be placed in some conspicuous place of the cart, &c.; and his name be entered with the commissioners of hackney-coaches, under the penalty of 40s. and every person may seize and detain such cart till the penalty be paid. On changing property, the names of the new owners are to be affixed, and to be entered with the commissioners of hackney-coaches, 30 Geo. II. c. 22. And stat. 24 Geo. III. ft. 2. c. 27. compels the entry of all carts driven within five miles of Temple-bar. By 13 Geo. III. c. 78. §. 11. a person, who leaves any cart or other carriage, &c. in any high-way, beyond the reasonable time allowed for loading or unloading, so as to obstruct the passage of any other carriage, &c. shall forfeit 10s. By 1 Geo. stat. 2. c. 57, by 24 Geo. II. c. 43, and, more generally, by 13 Geo. III. c. 78, it is enacted, that if the driver of any cart, car, dray, or waggon, shall ride upon any such carriage in any street or highway, not having some other person on foot or on horseback to guide the same (such carriages as are conducted by some person holding the reins of the horse or horses drawing the same excepted);—or if the driver of any carriage whatsoever, on any part of any street or highway, shall by negligence or wilful misbehaviour cause any hurt or damage to any person or carriage passing or being upon such street or highway;—or shall quit the highway and go on the other side of the hedge or fence inclosing the same; or wilfully be at such distance from such carriage, whilst it shall be passing upon the highway, that he cannot have the direction and government of the horses or cattle drawing the same: or shall, by negligence or wilful misbehaviour, prevent, hinder, or interrupt the free passage of any other carriage, or of his majesty's subjects, on the said highways; or if the driver of any empty or unloaded waggon, cart, or other carriage shall refuse or neglect to turn aside and make way for any coach, chariot, chaise, loaded waggon, cart, or other loaded carriage; or if any person shall drive, or act as the driver, of any such coach, post chaise, or other carriage let for hire, or waggon, wain, or cart not having the owner's name (as by this act is directed) painted thereon, or shall refuse to discover the true christian and surname of the owner of such respective carriage; he shall on conviction by confession, view of the justice, or oath of one witness, before one justice, forfeit any sum not exceeding 10s., in case such driver be not the owner of such carriage; and if he be the owner, then any sum not exceeding 20s.; and in default of payment be committed to the house of correction for any time not exceeding one month, unless the same be

sooner paid. And every such driver offending in either of the said cases, may by authority of this act, with or without any warrant, be apprehended by any person who shall see such offence committed, and shall be immediately conveyed or delivered to a constable or other peace officer, to be conveyed before a justice, to be dealt with according to law. And if any driver, in any of the cases aforesaid, shall refuse to discover his name, the justice may commit him to the house of correction for any time not exceeding three months, or may proceed against him for the penalty by a description of his person and the offence, and expressing in the proceedings that he refused to discover his name.

And for the better discovering of offenders, the owner of every waggon, wain, or cart, and also of every coach, post chaise, or other carriage, let to hire, shall cause to be painted, upon some conspicuous part of his waggon, wain, or cart, and upon the pannels of the doors of all such coaches, post chaises, or other carriages, before the same shall be used in any public highway, his christian and surname and place of abode, in large legible letters; and continue the same thereupon so long as such carriage shall be used upon any highway: and the owner of every common stage waggon or cart shall, over and above his christian and surname, cause to be painted on the part and in the manner aforesaid, the following words, *common stage waggon or cart*, as the case may be. And every person using any such carriage as aforesaid upon any highway, without the said names and descriptions respectively, or causing to be painted thereon any fictitious name or place of abode, shall forfeit not exceeding 5l. nor less than 20s.

“Taxed carts,” constructed, kept, and used under the regulations of the stat. 43 Geo. III. c. 99, are exempted from the annual duty of 5l. 5s. charged for carriages with less than four wheels and drawn by one horse. Such carriages are thus described: they shall be built wholly of wood or iron, without any covering other than a tilted covering, and without any lining or springs, made of iron, wood, leather, or other materials, and with a fixed seat, without flings or braces, and without any ornament whatever, other than paint of a dark colour, for the preservation of the wood or iron only, and which shall have the words “a taxed cart,” and the owner's christian and surname and place of abode, marked or painted on a black ground in white letters, or on a white ground in black letters, on the outside of the back pannel or back part of such carriage, in words at full length, and of a breadth in proportion, and the price of which (repairs excepted) shall not have exceeded, or the value thereof shall not at any time exceed the sum of 12l. sterling. For such a carriage kept by any person for his own use, and not for hire, the annual duty to be paid is 1l. 4s. The exemption from all duties specified in the aforesaid act extends to any cart kept to be used wholly in husbandry, or in the carriage of goods in the course of trade, and whereon the name and residence of the owner, and the words “common stage cart” shall be legibly painted; although the owner, or his or her servant, shall occasionally ride therein or thereon when laden, or when returning from any place to which, or when going to any place from which any load shall have been or shall be to be carried in such carriage, or for conveying the owners thereof or their families to or from any place of divine worship on Sunday, or on Christmas-day, or on Good Friday, or on any day, appointed for a public fast or thanksgiving, or for carrying persons going to or returning from the election of members to serve in parliament.

Casting

CASTING, in *Foundry*, is the running of a melted metal into a mould prepared for that purpose.

The great importance of a knowledge of casting to a mechanic, on account of the vast quantities of cast-iron now used in machinery, has induced us to give a particular description of this branch of the founder's art.

There are three sorts of casting, 1. *open sand casting*; 2. *sand casting between flasks*; and 3. *loam-casting*; in most of which, an exact pattern, usually of wood, of the subject to be cast, is given to the founder.

1. Most articles, every part of whose surface on one side is in the same plane (which we will call the horizontal plane), and every parallel section of which is of the same size in every part as the horizontal plane, or constantly decreasing as they recede downwards from it, and the edges of all which sections fall within perpendiculars, let fall from the edges of the plane immediately above it, may be cast in *open sand*: because, as the founders express it, every such pattern will *lift* out of the sand, wherein it has been imbedded as deep as its upper or plane surface, to form the mould for the metal.

The floor of every foundry is for many feet deep composed of a loamy sand (of which great quantities are brought to London from near Woolwich) so that deep pits may be dug, to bury large moulds in. (See *Foundry*). An example of open sand-casting is shewn in *Plate of Casting*, *figs. 1 and 2*, which represent the arms of a large wheel, the rim of which is to be screwed on by the flanches *a, a*, *fig. 1*; *b b* is the arm; *d* is a rib cast with it to strengthen it, the other side of the arm must be plain; *e* is the opening through which its shaft is to pass. In the place where the mould is to be made, a layer of sand, *c d*, *fig. 2*, is lightly sprinkled through a sieve on the floor, and the pattern *A* is pressed down into it, perfectly level; the next operation is shovelling the sand up all round, level with the top of the pattern, and ramming it down, with a tool, *fig. 4*; a sponge is then used for slightly wetting the sand all round the edges of the pattern to make it adhere together; the next operation is lifting the pattern out of the sand by one or more screws, *fig. 5*, screwed into the wood; if the pattern is small, this is done by one or more men, but in very large works it is done by a crane; the cores for the bolt holes through the flanches, *a, a*, *fig. 1*, are made by sticking pieces of dried clay in the sand in the proper places, and the core for the hole *e*, made of clay, is also set in its place; the workman then uses a pair of bellows for blowing away any small pieces of sand which may have fallen into the mould. It is now ready for filling with metal; in small works this is done by ladles, and in large, by small ditches made in the sand, from the mould to the mouth of the furnace: when the mould is filled, the metal is covered up with sand to keep the air from it.

II. *Sand-casting between flasks* is used for those articles which if they were cut into two or more pieces (provided the cutting planes were parallel to each other) each separate

piece might be cast in open sand. A specimen of this sort of casting is shewn in *fig. 6*, which is an endless screw and spindle, often composed of cast iron. *AB* and *CD* are frames called flasks, with four handles, *c, d, e, f*, to lift by; *a, b, l, m*, are iron points fitting into holes *g, h, i, k*, in the other flask *CD*, for ascertaining when they fit each other. The under flask *CD* is set upon a board, filled with sand, and the same is rammed tight into it: the workman then takes the pattern *EF*, and presses one half of it into the sand, and smooths the sand up to the sides of the pattern with a trowel, *fig. 3*; he then sets the empty flask, *AB*, over the other, *CD*, putting its points *a, b, l, m*, into the holes *g, h, i, k*; and after sprinkling some sand which has been burnt over the sand in the under flask, he fills the upper one with sand, and rams it down; he next with a piece of wood, put through the sand in the upper flask, makes a hole shewn at *p*, to pour the metal through; the upper flask, *AB*, with the sand in it, is then lifted off by men, or in large works, by a crane, and the pattern, *EF*, lifted out; the flask, *AB*, is then put on again, and heavy weights are laid on it to keep it down, ready for casting. It must be observed, that at every highest point of large moulds a small hole must be made through the sand in the upper flask, to allow the air to pass out of the mould when the metal is poured in.

Figs. 7, 8, 9, and *10* shew the manner of casting a cog-wheel with eight arms, all of which are ribbed on both sides. The pattern is laid upon a board with the face shewn in *fig. 7*, upwards; an empty flask is laid upside downwards over the board and pattern; it is filled with sand and rammed tight; a plain board is then laid upon the flask, and two men turn it over, bringing the pattern to the top, as shewn in *fig. 10*; the workman with a small trowel, *fig. 3*, then digs all the sand out of the space *AA*, *fig. 10*, between each arm, leaving it level with the tops of the ribs, *a, b, c, d*, &c. *fig. 7*; into each of the spaces thus formed, a piece of iron plate, *fig. 8*, cut to suit the same, is laid; it has an iron rod, *a*, projecting from the upper side and two points, *b, d*, at the under side, which are inserted into the sand between the arms, so that the two edges, *e, f*, touch the upper edge of the arms *a, b*, of the wheel, *fig. 7*. The spaces above these plates are then filled with sand and rammed down level with the rest of the sand in the flask: burnt sand is then sprinkled over the lower flask to prevent the sand which is now to be rammed into the upper flask, *CD*, from adhering to that in the lower; the holes for the metal are next made through the top flask, and it is then taken off; the iron plates and the sand upon them are taken out by the ends of the iron, *a*; the sand round the pattern is slightly wetted, and the cogs of the wheel are taken out one by one (for which purpose they are only fixed on by a dovetailed groove cut in the rim, see *M*) and then the whole wheel is lifted out by the screws, *fig. 5*; the iron plates

plates are then put again in the place where they stood before, being determined by the holes which the points, *b, d*, made in the sand. The hole *H* through the wheel, which is to receive the shaft, is solid in the pattern, and a projection of the same size as the intended hole is fixed on; this projection forms a recess, *k*, *fig. 10*, in the sand, which is to determine the place of the core, *M*, *fig. 9*, for the hole, which is made in a separate pattern of well tempered clay or wet loam and dried. The upper flask, *CD*, is then put on again, and loaded with weights ready for casting. In casting large cog-wheels, &c. flasks are often wanted as large as 20 feet on each side; to keep the sand from falling out, bars of wood are bolted across the flask, into which long nails are driven, before it is filled, to keep the sand together. These large flasks are lifted by a crane.

III. *Loam-Casting* is used for bulky articles, as cylinders, large pipes, boilers, cauldrons, &c. &c. We will begin by describing the manner of forming the mould for a large cylinder: *A*, *fig. 11*, is a beam of the building; *BB* is a spindle with three or four holes, *dc*, through it, to fix an iron arm *D* in, at different heights by a nut; *EE* is a board, that can be firmly fixed between the bars *D* and *F*, by two clamps, *G, H*: the operation is begun by laying an iron ring *L* upon the ground, and adjusting it so as to be concentric to the spindle *B*; a cylinder of brick-bats and clay or wet loam, instead of mortar, is then built upon it, some inches less in diameter than the intended cylinder, for which this is to form a core; the bricks are strongly bound together with iron hoops, nealed wire, &c. and a fire is then lighted in it. When the loam used with the bricks is dry, a coating of loam is spread over it, and is smoothed by turning the board *EE* round it. This coat makes it of the proper size for the inside of the cylinder to be cast, and is called the core of the mould; another cylinder is built, plastered, and smoothed in the same way, except that no hoops are used, whose diameter is the same as the outside of the cylinder to be cast; when it is finished, it is covered with charcoal ground with water like paint, laid on with a brush; and a thin coating of loam is laid on; this is bound round with hoops, and to these, four hooks are fixed to lift it by; a thick coat of loam and hair is then laid over it. When all these are dry, a man gets into the cylinder, and with a small pick pulls down all the bricks in the inside cylinder, and then with a trowel cuts away all the loam, leaving the inside of the external cylinder (which is called the mould) quite smooth; this is effected by the coat of charcoal, which prevents the two coats of loam from adhering together.

A deep pit is now dug, in some convenient part of the foundry, into which the core is let down by a crane; an apparatus, shewn in *fig. 12*, is used for slinging it to the crane, *A B D E* is a wrought-iron cross, the arms of which are strengthened by ties going through the ring *F*, by which it is hooked to the crane-rope or chain; on each of the four cross-bars, a ring with a hook, *abde*, is loosely fitted; to these hooks ropes which pass through the hooks on the mould are fastened, in the core these ropes go round the stubbs, *l, l*, of the ring *L*, *fig. 11*. The mould can always be made to hang perpendicularly, by sliding the hooks, *a, b*,

c, d, nearer to or farther from the center of the cross. When the core is set down in the pit, the mould is let down over it by the same means, and when they are adjusted, the sand is thrown in, and rammed round, about half the height; a flat cover of dried loam is then put on the top of the mould and core, and round pieces of wood are put in the holes which had before been made in the cover for pouring the metal in at. The burying of the mould is then completed: when it is all levelled. The sticks which keep open the holes for the metal are carefully pulled out, and small ditches made from the furnace to them, ready for casting.

Fig. 13, shews the method of making the mould for an air-vessel (see our article *PUMP*); the core, *A*, is built of bricks, plastered with loam and turned by the machine, *fig. 11*, as before described; the edge of the board, *EE*, being cut to the proper curve; another is then built of the same size and form as the outside of the vessel to be cast, with a projecting ring or flaunch at the bottom; this, after being turned, is painted with charcoal, and the mould made upon it as in the last case; it is plain, that from the shape of the core the mould cannot be lifted off, nor can a man readily get in, to take out the bricks as in the case of a cylinder; the mould must therefore be sawn in half, *B G*, with a fine saw, to get it off; it is then put together again round the core *A*, and the crack is plastered up with loam. To describe the more complicated cases of this kind of Casting, as the nozzles or valve-boxes and pipes of steam-engines, &c. &c. would far exceed our limits.

CASTING of gold, silver, or copper, in plates. See *COINING*.

CASTING, in *Joinery*, &c. Wood is said to be cast or warped, when, either by its drought or moisture, or the drought or moisture of the air, or other accident, it shoots or shrinks; in prejudice to its flatness or straitness.

CASTING of lead on cloth, is the using of a frame or mould covered with woollen cloth and linen over it, to cast the lead into very fine sheets.

CASTING of lead on sand, is done by means of a large frame or trough nearly full of sand, which is made perfectly level, and imprinted with any device from moulds pressed down in the sand: the lead is then turned out of the kettle into a receiver or trough, and poured on the sand, whilst two persons slide a gauge or lath, of such thickness as to leave a space between it and the sand answering to the substance of the lead, along the edges of the frame; the surplus runs into reservoirs by channels made in the sand. See *CASTING*, in *Foundry*.

The goldsmiths use the bone of the CUTTLE-fish, to mould and cast their lesser works of gold and silver; that bone, when dried, being reducible to a kind of a fine pumice, very susceptible of all impressions.

CASTING in *fluc* or *plaster*, is the filling with fine liquid plaster a mould that had been taken in pieces from off a statue or other piece of sculpture, and run together again. There are two things to be observed with regard to the mould: the first, that it be well soaked with oil before the plaster be run, to prevent its sticking: the second, that each piece whereof it consists have a packthread, to draw it off the more easily when the work is dry. See *CAST*.

Fig. 1.

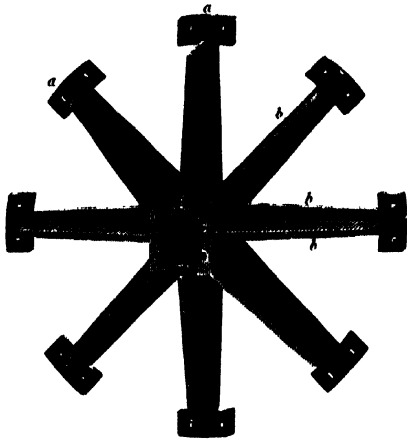


Fig. 2.



Fig. 3.



Fig. 4.



Fig. 7.



Fig. 8.



Fig. 6.

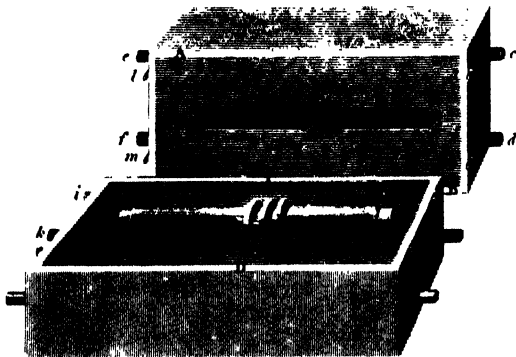


Fig. 10.

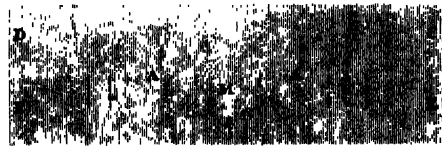


Fig. 11.

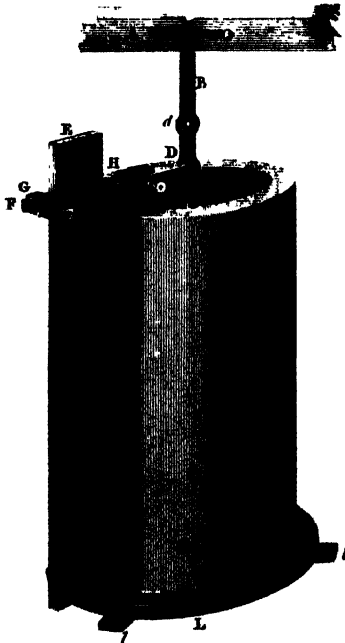


Fig. 12.

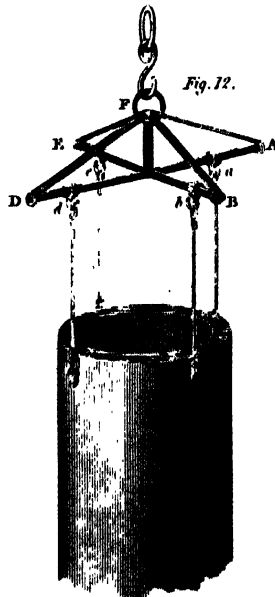
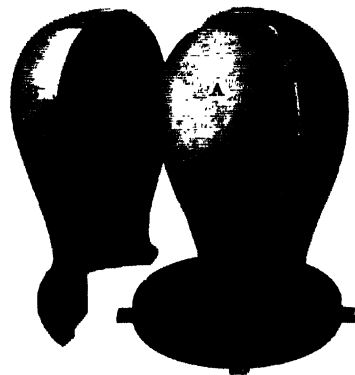


Fig. 13.



Addenda & Corrigenda.

ACETIC ACID. It is now universally admitted by chemists, that the acetic acid differs in no respect from common vinegar, or what was formerly termed *acetous* acid, but in the degree of concentration only. This opinion, first advanced by Adet, has lately been fully confirmed by the experiments of Darracq and Proust. What has been said, therefore, on the subject of *acetous* acid and *vinegar* in the Cyclopædia, is to be understood as applicable to dilute *acetic* acid; and the salts termed *acetites* are to be considered as *acetates*. The following facts are important, and deserve a place here.

The specific gravity of acetic acid does not enable us to determine its strength. The specific gravity is stated by Dr. Thomson to be a maximum when the liquid is a compound of one atom, and three atoms water. When the proportion of water is either increased or diminished, the specific gravity diminishes. Acid composed of one atom real acid and one atom water, and acid composed of one atom real acid and nine and a half of water, are stated by the same chemist to have the same specific gravity.

The following table, drawn up chiefly from the experiments of Mollerat by Dr. T., exhibits the specific gravity of acetic acid of various strengths.

Atoms.		Weight of		Sp. Gr.
Acid.	Water.	Acid.	Water.	
1	+	100	14.78	1.0630
		2	100	1.0742
		3	100	1.0770
		4	100	1.0791
		5	100	1.0800
		6	100	1.0763
		7	100	1.0742
		8	100	1.0728
		9	100	1.0658
		10	100	1.0637
		11	100	1.0630

Acetic acid of the sp. gr. 1.063 is the strongest that can be procured. It crystallizes at the temperature of 55°, and the crystals melt slowly when heated to 72½°. This had been long ago observed by Courtenvaux. Lowitz has proposed an ingenious method of obtaining it of the requisite degree of strength to crystallize. This consists in making distilled vinegar into a thick paste with well-burnt charcoal, and exposing the mixture to a temperature of 212°. The watery part is driven off, and the acid remains. The acid itself may be separated by a higher degree of heat, and thus obtained in a very concentrated state. It is commonly necessary, however, to repeat the process before it can be made to crystallize.

Mr. Chenevix, by distilling the *acetates*, obtained a peculiar substance different from acetic acid, and which he has denominated *pyro-acetic* spirit. The acetates of potash

and soda gave a greater proportion of this principle than any of the metalline acetates; but when the acetate of barytes is distilled, the whole liquid product consists of this spirit without any mixture of acid whatever. No other genus of salts tried, such as the oxalates, tartrates, or citrates, yielded this spirit, nor was acetic acid converted into it by heat.

Pyro-acetic spirit is a white and limpid fluid. Its taste is at first hot and acrid, but it becomes cooling and rather urinous. Its smell is peculiar, and is compared by Mr. Chenevix to that of a mixture of oil of peppermint and bitter almonds. Its specific gravity is .7864. It burns with a flame, white exteriorly, but of a fine blue within, and leaves no residue. It boils at a temperature of 165°. It mixes with water, alcohol, and volatile oils, in any proportion. With hot olive-oil it also mixes in any proportion; but with that oil cold it only mixes in certain proportions. When hot it dissolves wax and tallow. It dissolves also a little sulphur and phosphorus, and is an excellent solvent of camphor. It dissolves potash, and becomes dark-coloured, but it may be obtained again unaltered by distillation. Strong sulphuric acid blackens and decomposes it. Nitric acid renders it yellow, and changes its properties. Muriatic acid renders it brown. When distilled with this acid a combination takes place, and a substance is formed possessing very different properties from muriatic ether. These properties are sufficient to shew, that the *pyro-acetic* spirit is a distinct substance, and differs entirely from alcohol, ether, and volatile oils. Of course, therefore, as Dr. Thomson observes, it deserves a distinct place among compound combustibles.

Many attempts have been made to analyse the acetic acid. Those most worthy of notice are by Gay Lussac and Thenard, and Berzelius. The former burnt a mixture of acetate of barytes and chlorate of potash. The results were carbonic acid and water. Berzelius's analysis was made on the same principles, but the salt he employed was supposed to be quite free from water. The following are the results of these celebrated chemists:

	Hydrogen.	Carbon.	Oxygen.	Acid.
Gay Lussac	5.629	+ 50.224	+ 44.147	= 100
Berzelius	6.35	+ 46.83	+ 46.82	= 100

If, with Dr. Thomson, we consider the results of Berzelius most entitled to credit, acetic acid consists of

3	atoms or proportions of hydrogen, weighing	0.375
4	_____ of carbon	3.000
3	_____ of oxygen	3.000

Or of ten atoms or proportions, and the weight of an integrant particle, will be 6.375; and this weight, as the same

TABLE III.—Malleable and Brittle Metals.

	Bismuth.	Antimony.	Arsenic.	Cobalt.	Manganese.	Molybdenum.
Gold - - - - -	B —	B —	B	B —	M	B
Platinum - - - - -	B	B	B			B —
Silver - - - - -	B —	B —	B	B		B
Mercury - - - - -	B	B	B	O	O	O
Palladium - - - - -	B —		B			
Rhodium - - - - -						
Potassium - - - - -	B	B	B			
Sodium - - - - -	B	B	B			
Copper - - - - -	B —	B —	M		M	S
Iron - - - - -	B +	B +	B	B	S	B
Nickel - - - - -	B		B +	B		S
Tin - - - - -	M	M? +	B		B	
Lead - - - - -	M —	M —	B	B		S
Zinc - - - - -	O	B +	B	O	O	O

ANTIMONY, in *Chemistry*. Several important additions have been lately made to our knowledge respecting this metal and its compounds, which we shall briefly notice here.

In describing this metal, we stated that Haüy had been unable to ascertain its primitive crystalline form. This indefatigable observer has at length, however, determined that the primitive form of its crystal is an octahedron, and that its integrant particles have the figure of tetrahedrons. The specific gravity of antimony, according to Hatchett, is 6.712. It melts at a low red heat, or about 810° of Fahrenheit; and after this, if the heat be raised, the metal evaporates.

The oxyds of antimony have been lately investigated with great care by Thenard, Proust, Bucholz, and Berzelius. According to Thenard, this metal forms no less than six oxyds; according to Proust and Bucholz, it forms only two; while according to Berzelius, it forms four. These discordancies arise from the great difficulty of the investigation. The protoxyd of Berzelius is obtained by exposing antimony to the air, or to the action of a galvanic battery. It is a grey powder. When acted upon by muriatic acid, it is separated into the protoxyd of Proust and metallic antimony. Hence Dr. Thomson remarks it is only a mixture of the two. The two oxyds of Proust are easily obtained, and possess specific characters. Berzelius has shewn that the second of them possesses the properties of an acid. The peroxyd of Berzelius is also readily obtained, though it is difficult to free it from water. This likewise possesses the properties of an acid. Hence, says Dr. Thomson, we know three oxyds of antimony. The grey protoxyd, the white antimonious acid, and the straw-yellow antimonic acid.

The following is the composition of the protoxyd of anti-

mony according to

	Proust.	Berzelius.	Thomson.
Antimony	100	100	100
Oxygen	22.7	18.6	17.775

Antimonious acid is composed, according to the same chemists, of

	100	100	100
Antimony	100	100	100
Oxygen	29.87	24.8	23.7

And antimonic acid of

	—	100	100
Antimony	—	100	100
Oxygen	—	37.2	35.556

The above results of Berzelius and Thomson are rather obtained by calculation than actual experiment, being founded on the supposed composition of sulphuret of antimony, which, according to Berzelius, is composed of 100 antimony and 37 sulphur, and according to Thomson, of 100 antimony and only 35.572 sulphur.

While such discordancies exist respecting the composition of the oxyds of antimony, it is impossible to fix with certainty the weight of its atom. Dr. Thomson, however, it may be proper to state, considers it as 56.25.

The two oxyds of antimony, denominated above the antimonious and antimonic acids, are capable, according to Berzelius, of combining with different bases and forming two sets of salts, the first of which may be termed antimonites, the second antimoniates.

The following is the method of preparing the antimonium tartarizatum, or tartrate of antimony and potash, according to the last edition of the London Pharmacopœia.

Take sulphuret of antimony pounded, two ounces; nitrate

of potash, one ounce; supertartrate of potash, two ounces; sulphuric acid *by weight*, two ounces; distilled water, a pint and a half. Mix the acid with half a pint of water in a proper glass vessel, and place it in a sand-bath. When moderately heated add by degrees the sulphuret and nitre previously well mixed together; and then apply heat till the whole of the water is driven off. Wash the remainder with distilled water until it comes off tasteless, and while the mass is yet moist mix it with the supertartrate of potash. To this mixture add a pint of distilled water. Boil the mixture, and when filtered put it aside to crystallize.

CANAL, col. 14, l. 44, add—The principal interior canals that are already (1818) completed in the United States are, the Middlesex canal, uniting the waters of the Merrimack river with the harbour of Boston, and the canal Carondelet, extending from Bayou St. John, a post of delivery in the Mississippi district, to the fortifications or ditch of New Orleans, and opening internal communication with lake Pontchartrain. The union of this canal by lakes with the Mississippi would, independently of other advantages, enable the government to transport with facility and effect the same naval force for the defence both of Mississippi and lake Pontchartrain, the two great avenues by which New Orleans may be approached from the sea. In 1816 or 1817, the state legislature of New York passed acts, appropriating funds for opening a navigable communication between the lakes Erie and Champlain and the Atlantic ocean, by means of canals, connected with the Hudson river. When this scheme, actually begun, is accomplished, and a communication opened by canals and lakes between lake Erie and the navigable waters of Hudson's river, and also between lake Champlain and these waters, the state of New York will soon become, in itself, a powerful empire.

Sheet Q q, instead of CANAL at the head of the page, insert in col. 1 and 2, CAN.

CANAL, p. 44, col. 2, l. 6 from the bottom, for thereon *r.* therein. P. 49, col. 1, l. 20, add—Mr. Chapman has lately (*viz.* in 1816) suggested to the editor, that this method, without complicated collateral aid, not had in contemplation, will be found to be impracticable; because the moment the descending crifton entered the lower canal, the equilibrium would be lost, and all counterbalance when the crifton had entered to such depth as to allow its contained vessel to go out.

For HARTLEPOOL CANAL *r.* HARTLEY CANAL; for Durham *r.* Northumberland; and for Hartlepool *r.* Hartley. CANAL, *Basingfloe*, col. 2, l. 3, after commences in, insert—Cooper's meadow, adjoining to the town of Basingfloe, and enters the river Wey about two miles above Weybridge; *dele*, l. 3, 4, 5, from Wey to Basingfloe; l. 18, after Lodden, add—The proprietors are prohibited from touching the Lodden, or any of the springs or streams that feed it.

CARBON, in *Chemistry*. The progress of chemical knowledge enables us to state, with greater accuracy and precision, the nature of some of the compounds of carbon, than at the period when this article in the Cyclopædia was written.

Carbonic Oxyd.—It has been shewn by Gay Lussac, that 100 measures of this gas require for complete combustion 50 measures of oxygen, and that the product is 100 measures of carbonic acid; hence it must be composed of one atom of carbon and one atom of oxygen, or 100 parts by weight will consist of

Oxygen	57.14
Carbon	42.86
	100.00

And its true specific gravity must be .9722, and 100 cubic inches of it must weigh, at a mean temperature and pressure, 29.652 grains. Carbonic oxyd has the property of combining with chlorine, and forming a peculiar compound, which its discoverer, Dr. Davy, has named PHOSGENE gas; which see.

Carbonic Acid.—When pure charcoal is burnt in oxygen gas, it has been shewn that the original bulk of the oxygen suffers no change. Hence it is obvious, that, by subtracting the specific gravity of oxygen from that of carbonic acid gas, we shall obtain the quantity of carbon existing in it. The specific gravity of oxygen gas is 1.11, and that of carbonic acid 1.52. Hence 100 parts, by weight, of carbonic acid will consist of

Oxygen	72.73
Carbon	27.27
	100.00

which correspond with two atoms of oxygen and one of carbon. See ATOMIC Theory.

Carburetted Hydrogen.—The specific gravity of carburetted hydrogen, according to Dr. Thomson, is .5555, and 100 cubic inches of it weigh 16.99 grains. It requires for its complete combustion twice its volume of oxygen gas, and produces exactly its own volume of carbonic acid; the only remaining product is water. Hence 100 parts, by weight, of this gas are composed of

Carbon	75
Hydrogen	25
	100

which correspond with one atom of carbon and two of hydrogen.

Olephant Gas.—The specific gravity of this gas, according to Dr. Thomson's experiments, is .974, and 100 cubic inches of it weigh 29.72 grs. It requires for its complete combustion three times its volume of oxygen gas, and produces, when burnt, twice its volume of carbonic acid gas, and a certain proportion of water. Hence 100 parts, by weight, of this gas are composed of

Carbon	85.71
Hydrogen	14.29
	100.00

which correspond with one atom of carbon and one of hydrogen.

The curious oil-like compound formed by the union of this gas with chlorine, has been lately examined by MM. Robiquet and Colin. They found that it is composed of one volume of chlorine united with one volume of olefant gas, and of course that its constituents, by weight, are

Olefiant gas	-	-	16.28
Chlorine	-	-	83.72
			<hr/>
			100.00

This oily liquid, which Dr. Thomson considers as a sort of *ether*, and hence names it *chloric ether*, burns with a green flame, and at the same time gives out copious fumes of muriatic acid and much soot. Its specific gravity at 45° is 1.2201, water being 1.000. It boils at 152°. At the temperature of 49°, its vapour is capable of supporting a column of mercury 24.66 inches in height. The specific gravity of this vapour was found by experiment to be 3.4434, which very nearly coincides with the above account

of its composition. When passed through a red-hot porcelain tube it is decomposed and converted into muriatic acid, and an inflammable gas containing hydrogen and carbon, while a copious deposit of charcoal is found in the tube. It is also decomposed when passed through red-hot oxyd of copper.

With respect to the *carbonates*, the numbers representing them will of course require a little adjustment; this can be easily done from the composition of carbonic acid stated above, and from the data given under *Atomic Theory*.

CARBONIC Acid Gas, col. 2, l. 5, add—According to the accurate experiments of Messrs. Allen and Pepys, recorded in the Phil. Transf. the weight of a cubic inch of this gas is .464 of a grain. Col. 3, l. 46, *r. milkinets*.